COUPLER DEVELOPMENTS AT CEA-SACLAY

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CERN WWFPC 23/06/2015

- 704 MHz FPC
  - HIPPI
  - ESS

- IFMIF 175 MHz CW FPC

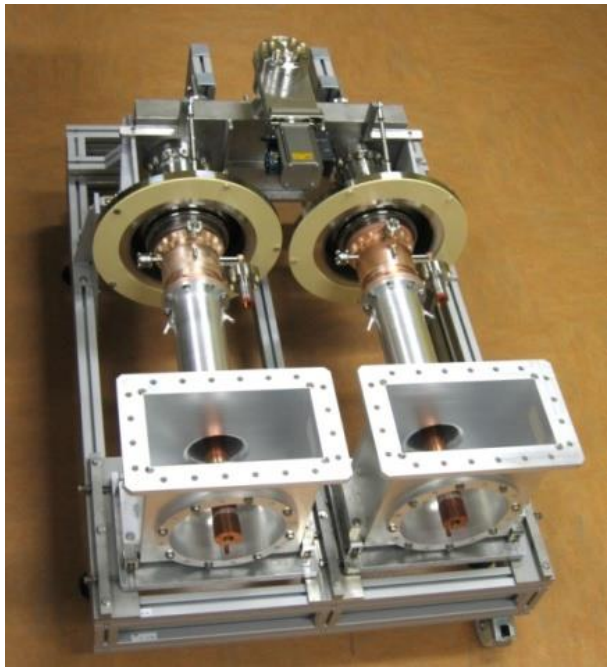
HIPPI FPC

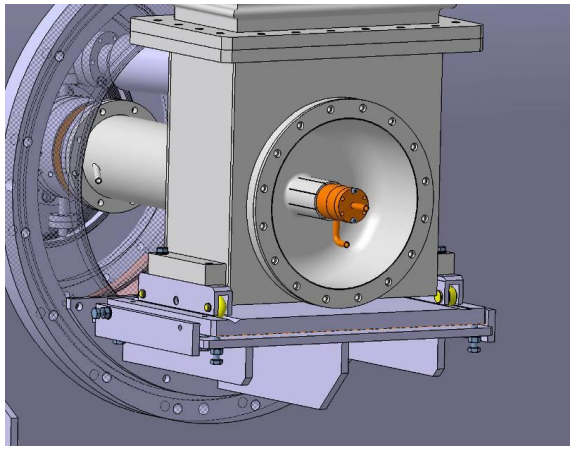
HIPPI = High Intensity Pulsed Proton Injector (part of FP6-CARE EU R&D programme)

Goal of programme was :

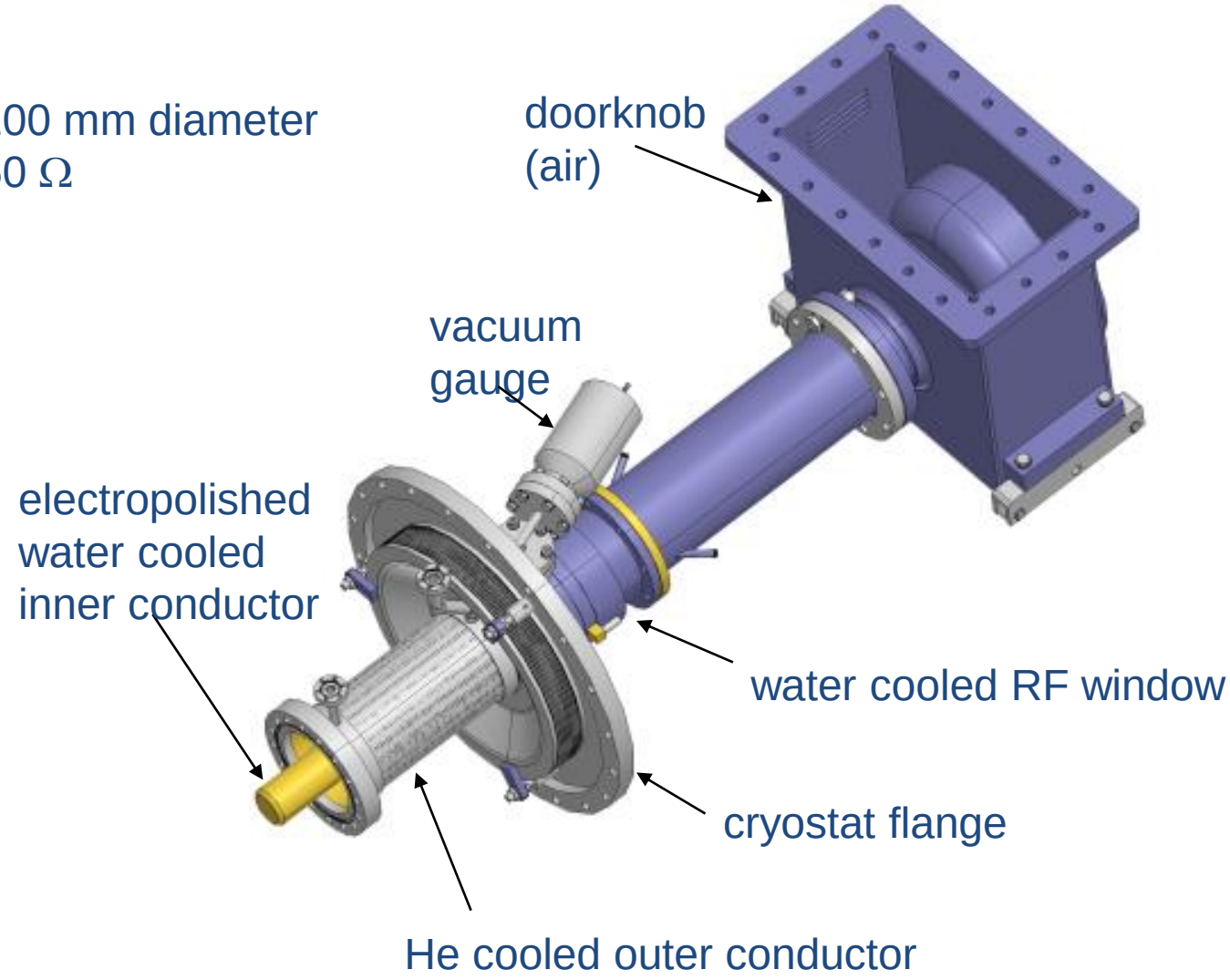
- Develop a 1 MW power coupler at 10% duty cycle
- Test it on a low beta multicell SRF cavity

CRYHOLAB Test cryostat requires horizontal orientation of the FPC
→ Mecanical assembly and Conditioning test stand were designed to mimmick horizontal setup of FPC

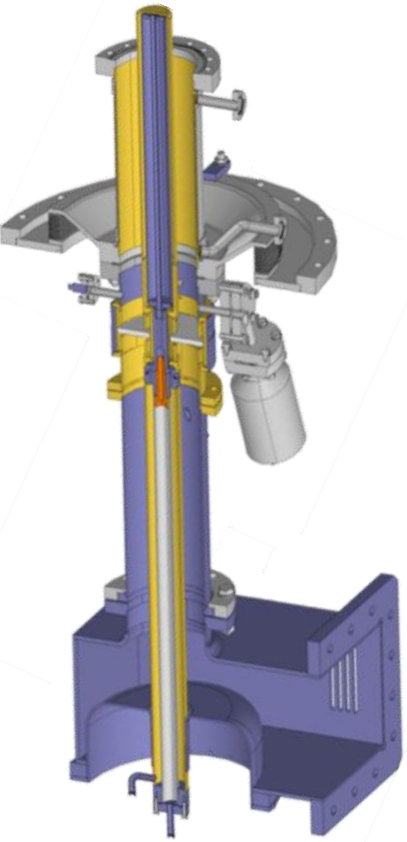


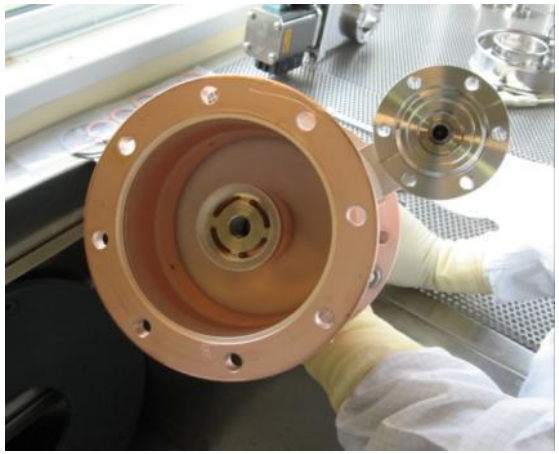


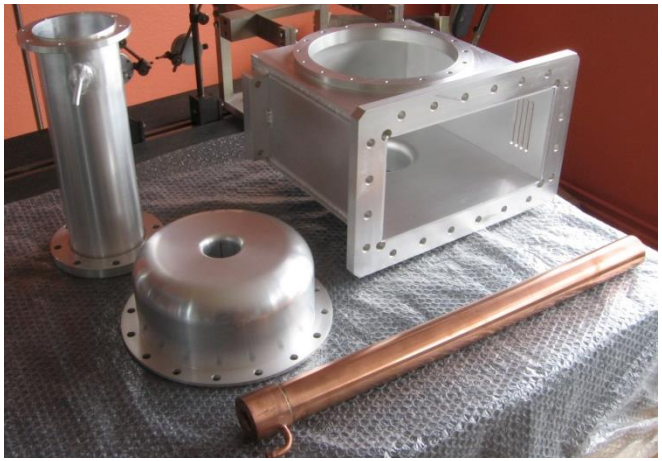
704 MHz -1 MW power coupler



704 MHz FPC components







Coupler – window (1)

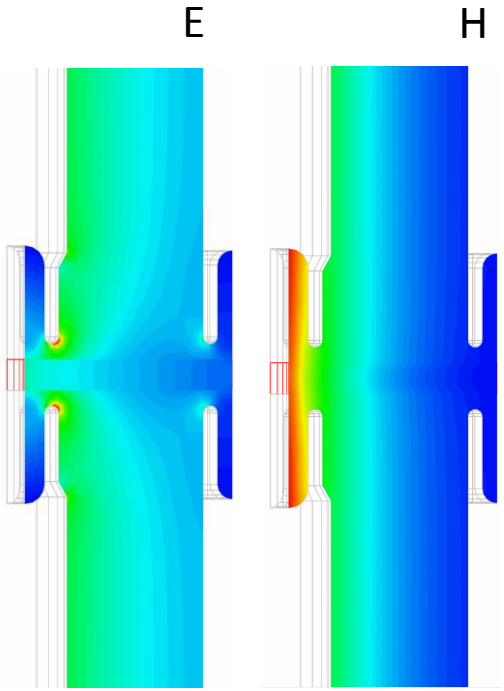
Matching calculations (HFSS)

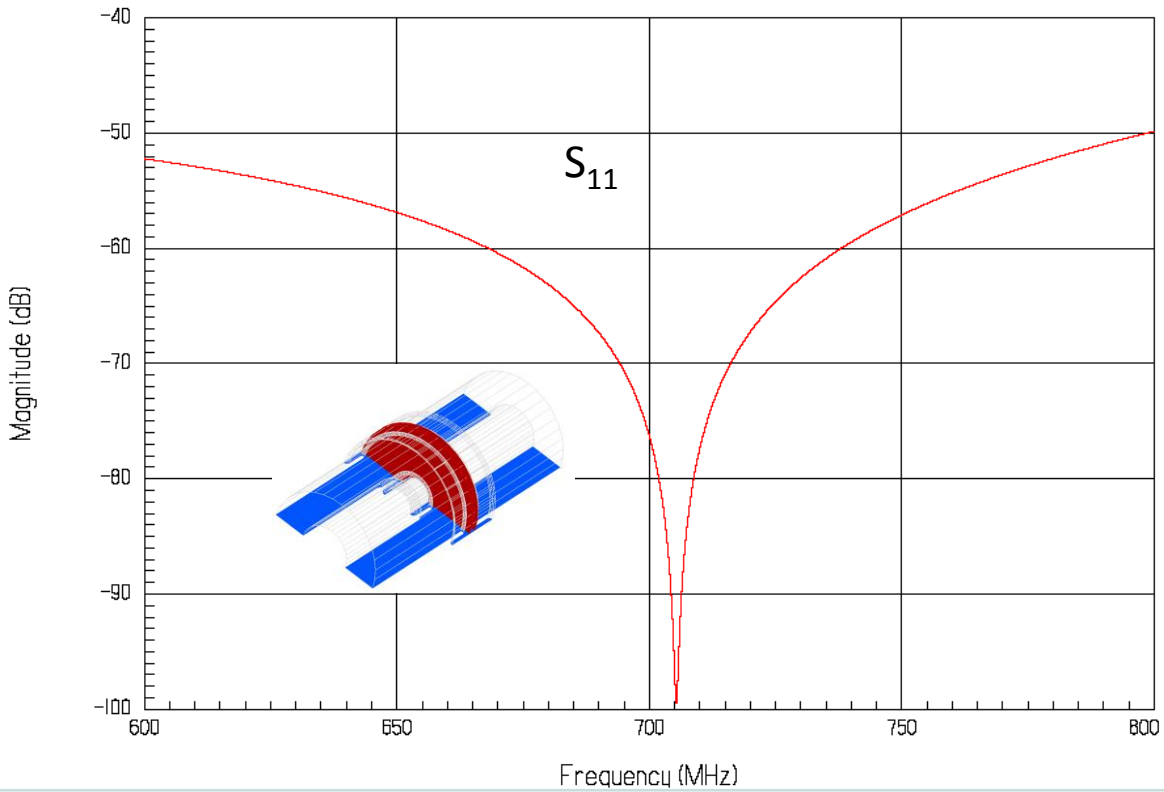
Starting from KEK-B / SNS geometry with double chokes

$\Rightarrow$ 100 mm diameter, 50 Ω

$\Rightarrow$ 704.42 MHz center frequency

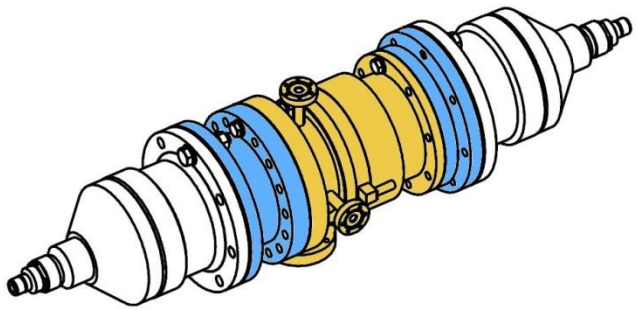
Large bandwidth design

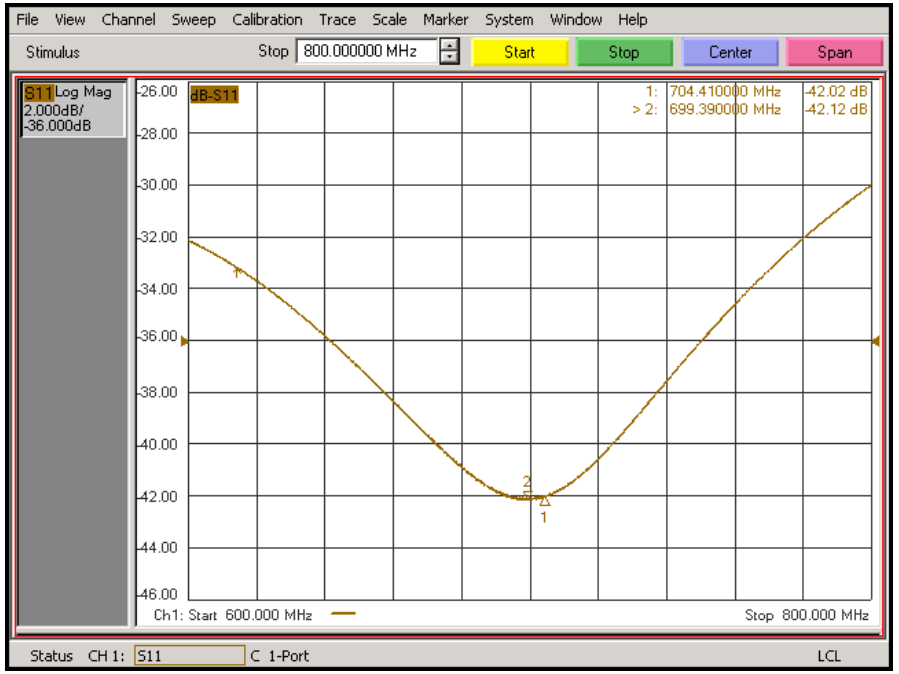




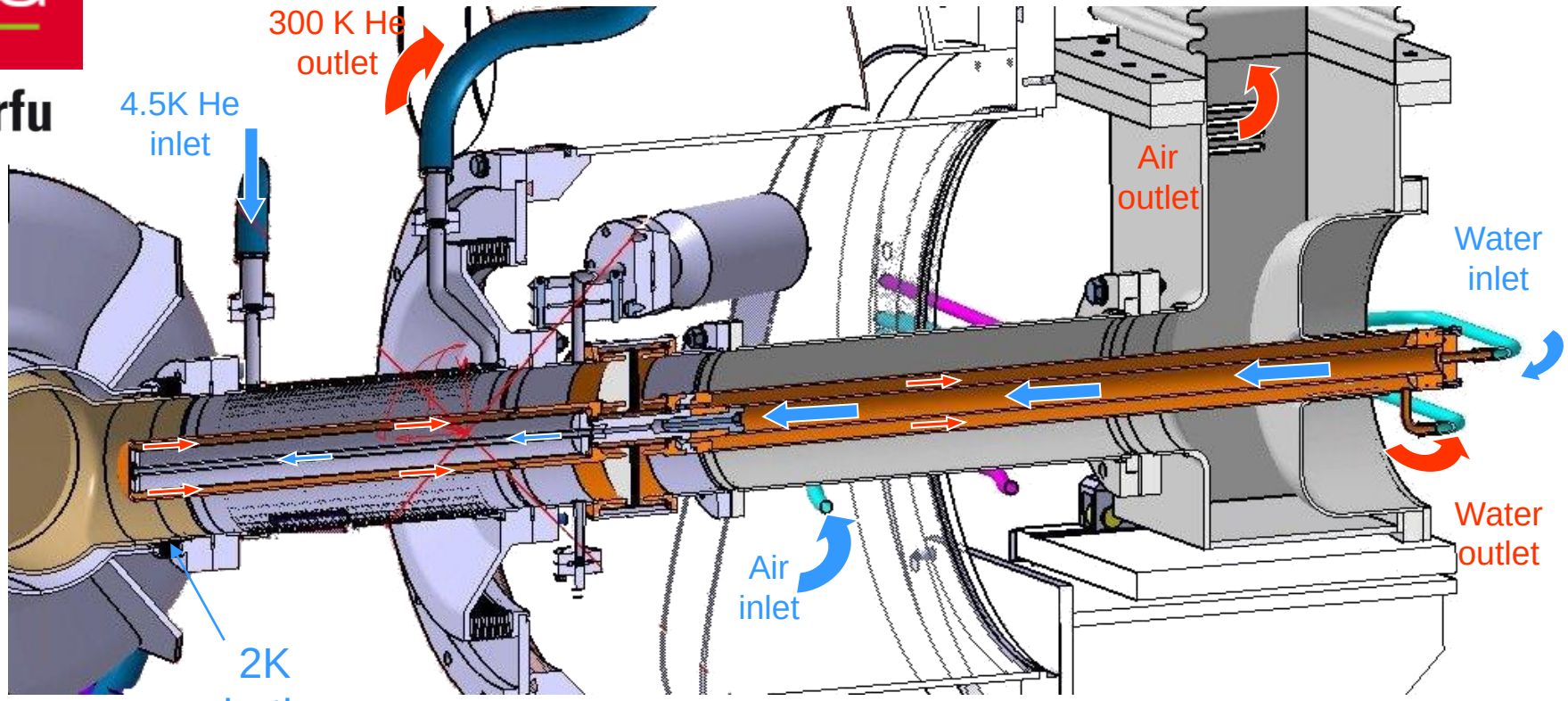
Coupler – window manufacturing prototypes

- 2 prototypes build by Toshiba (IPNO & Saclay)
- Antenna supposed to be welded later on but it was considered too difficult by the manufacturer
- Was used for RF measurements, leak test and pressure test of water cooling channels





Coupler cooling



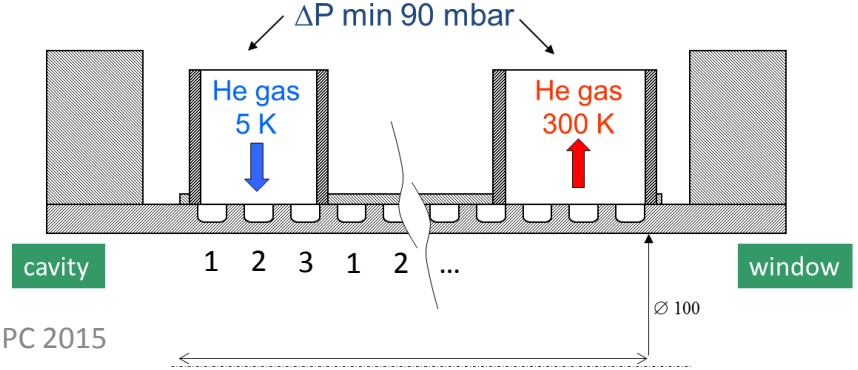
Air side

- blown air on the ceramic
- Internal conductor (IC) water cooled

Vacuum side

- Outer conductor (OC) He cooled
- IC water cooled
- ceramic outer water cooling channel

He cooling channel capable of up to 100 W extraction (3 spiral channels)



RF power test stand at 704 MHz

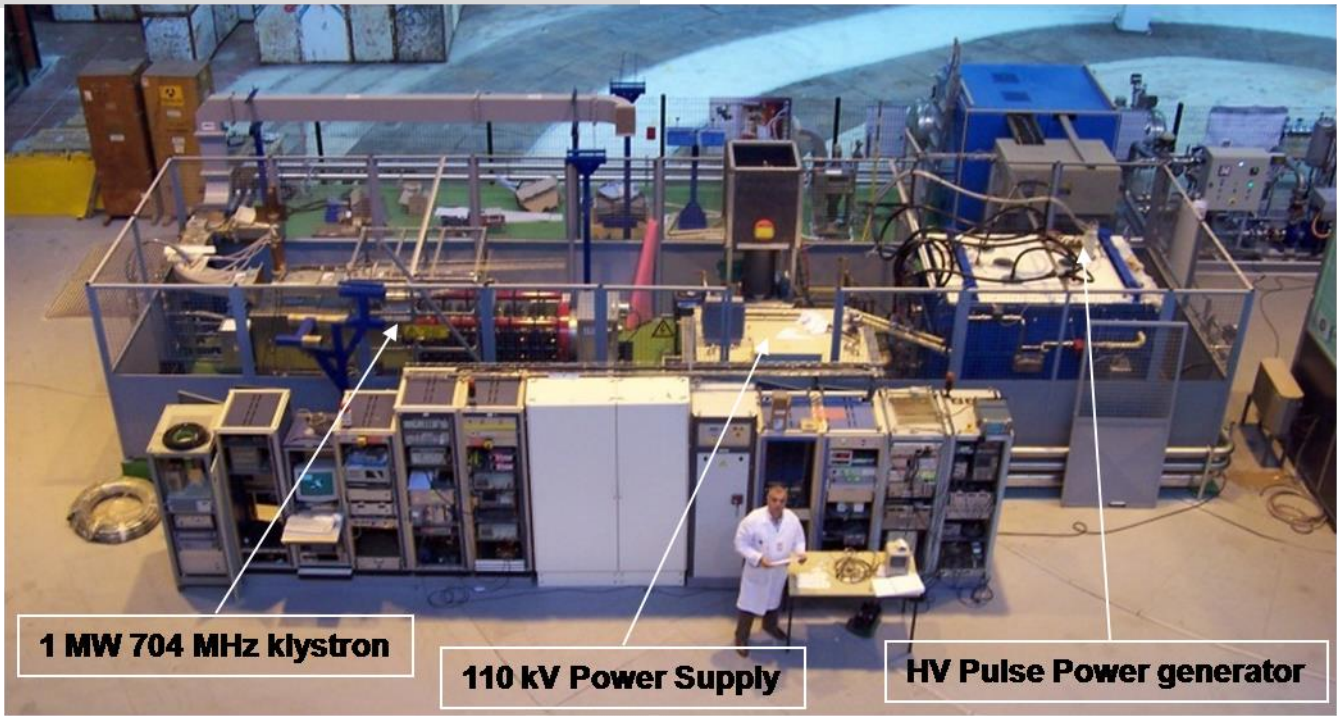
Running since 2008:

Nominal parameters :

- Peak power : 1MW (1.2 MW for a short period)
- Repetition rate : 50 Hz
- RF pulse length : 2 ms

Updated for ESS tests :

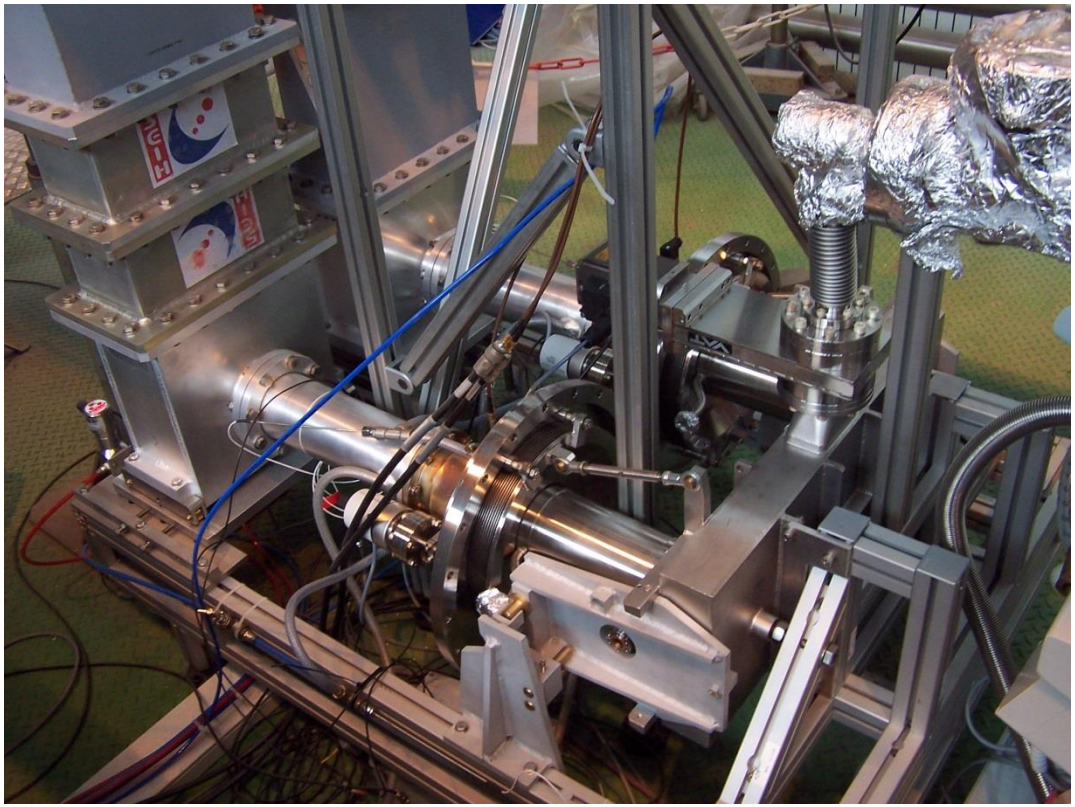
- Peak power : 1MW (1.2 MW for a short period)
- Repetition rate up to : 25 Hz
- RF pulse length : 3 ms



Coupler test stand with HIPPI couplers

Travelling wave and standing wave processing are performed sequentially

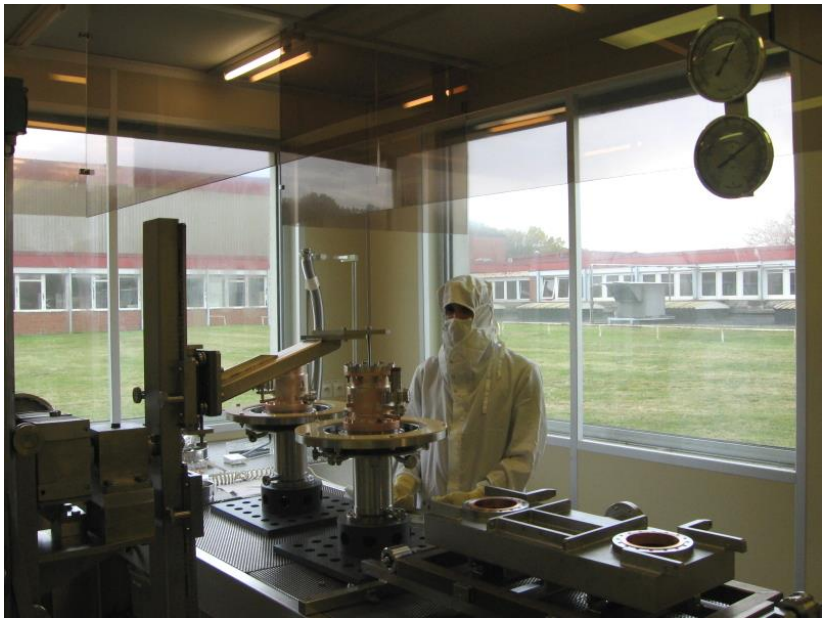
HIPPI test stand



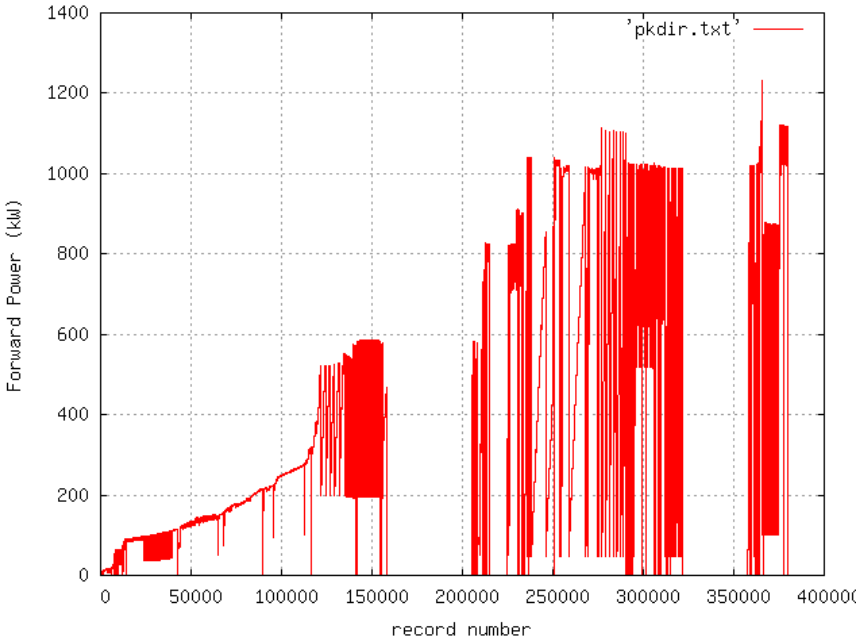
Coupling waveguide:

- Electrolytic copper coating was very difficult to achieve due to the poor access from the two 100 mm ports only
- Difficult to control the quality of the Cu layer, and clean

Coupler preparation in clean room

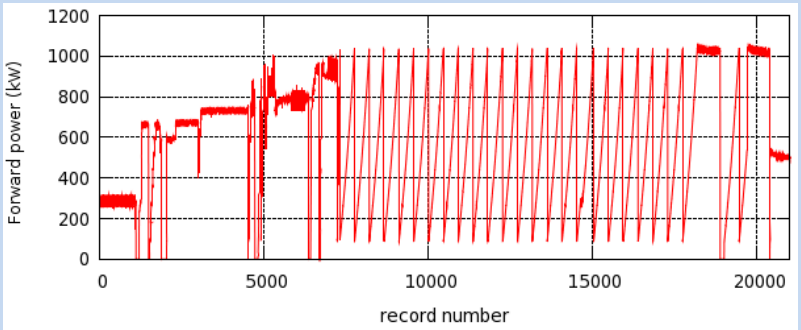


HIPPI couplers high power tests main results



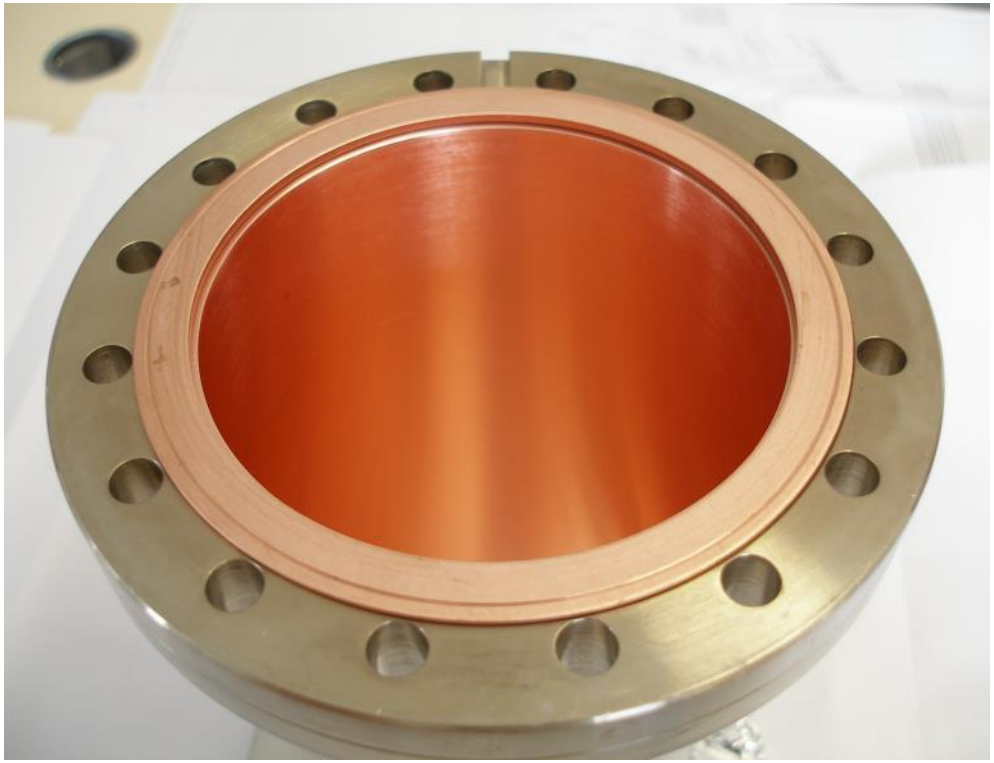
TW on conditioning test stand

1 pair tested up to 1.2 MW, 10% duty factor



Test of the HIPPI power coupler on the HIPPI cavity at 1.8 K, full reflection

100 mm outer conductor



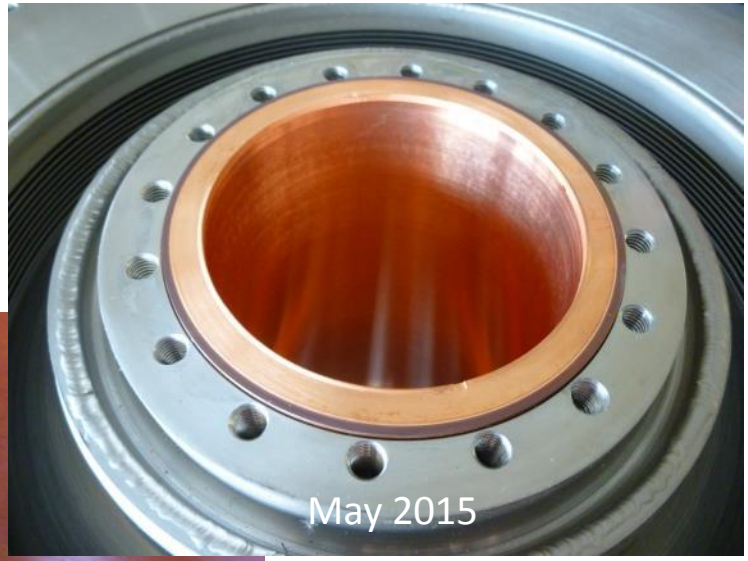
10 μm Cu layer

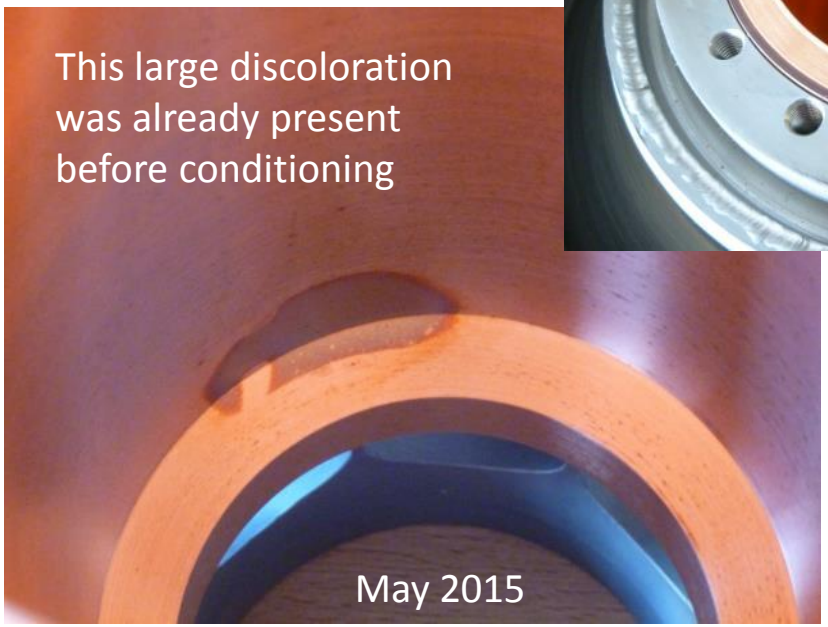
Magnetron Sputtering performed at CERN (S. Calatroni)

HIPPI coupler after 4-5 years storage

Example of special tapered 100-80 mm outer conductor for use with a INFN

- conditioned only in SW (single item available)
- Run on a 5-cell SRF cavity
- Stored under N2 gaz since 2011
- Opened in may 2015

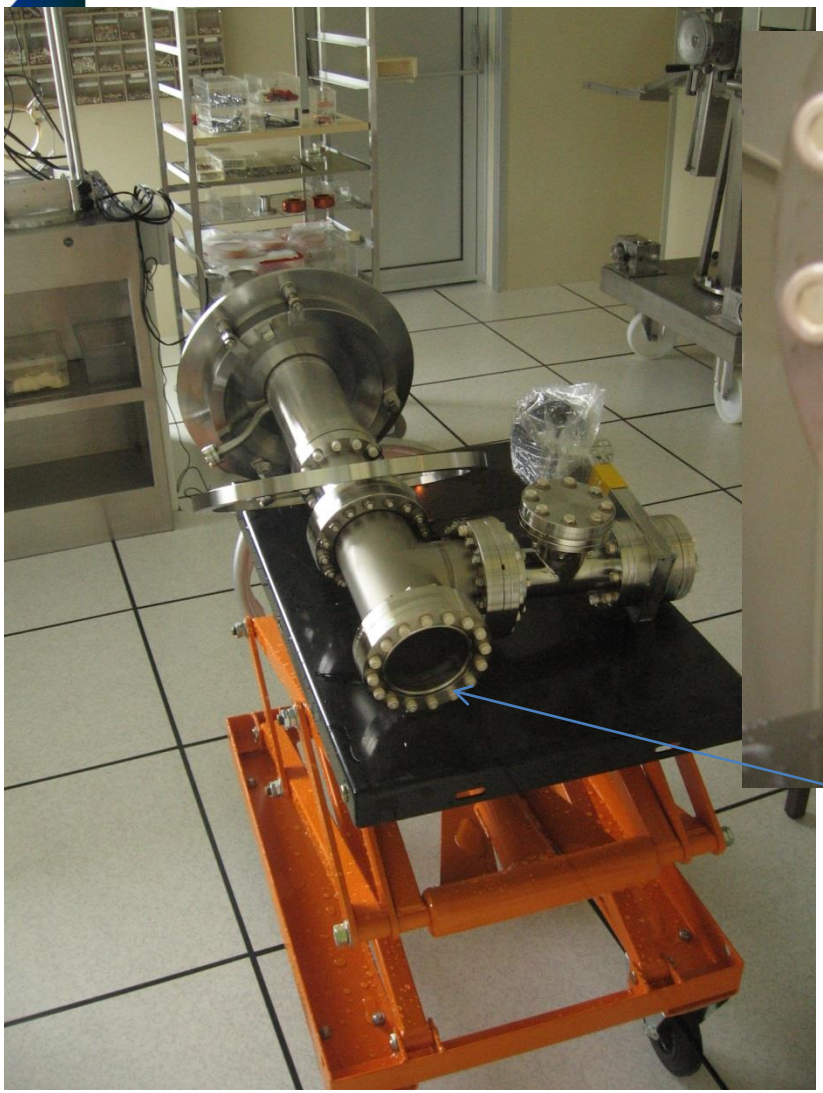


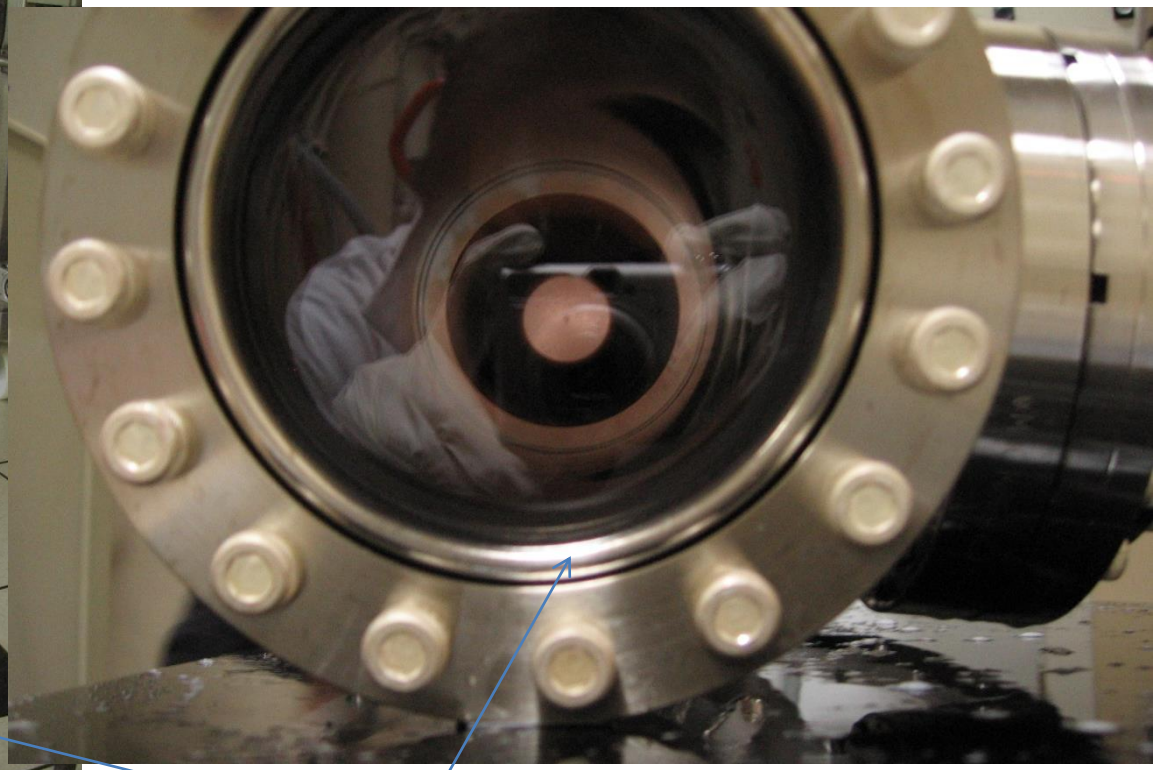


No impact observed during cavity operation

~1mm sized spot discolorations more visible after 5 years

Single FPC conditioning setup for the tapered outer conductor

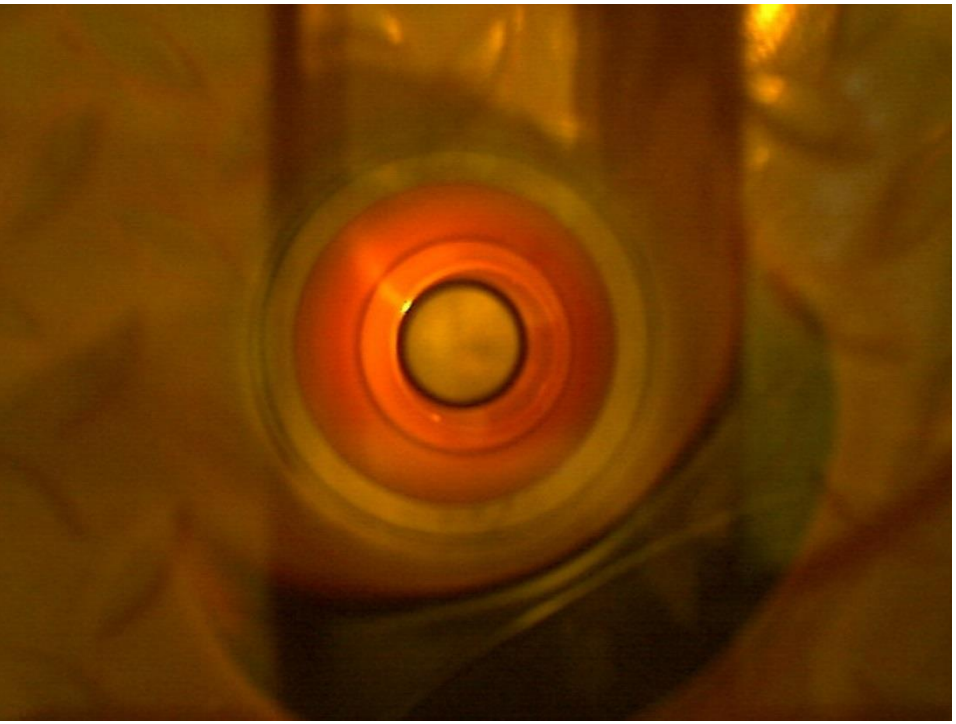


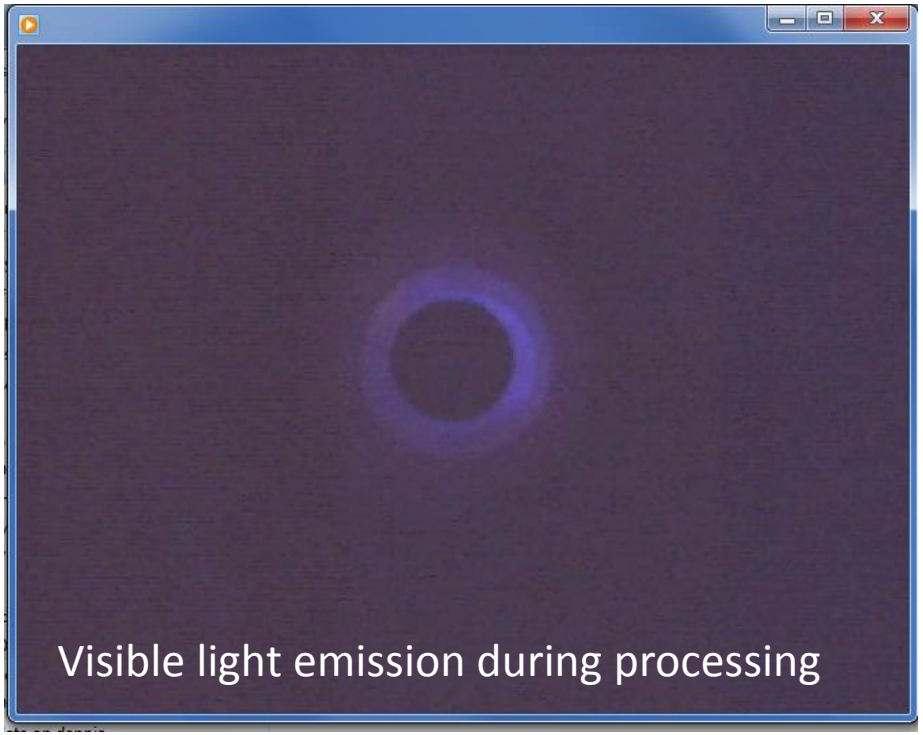


Large optical window

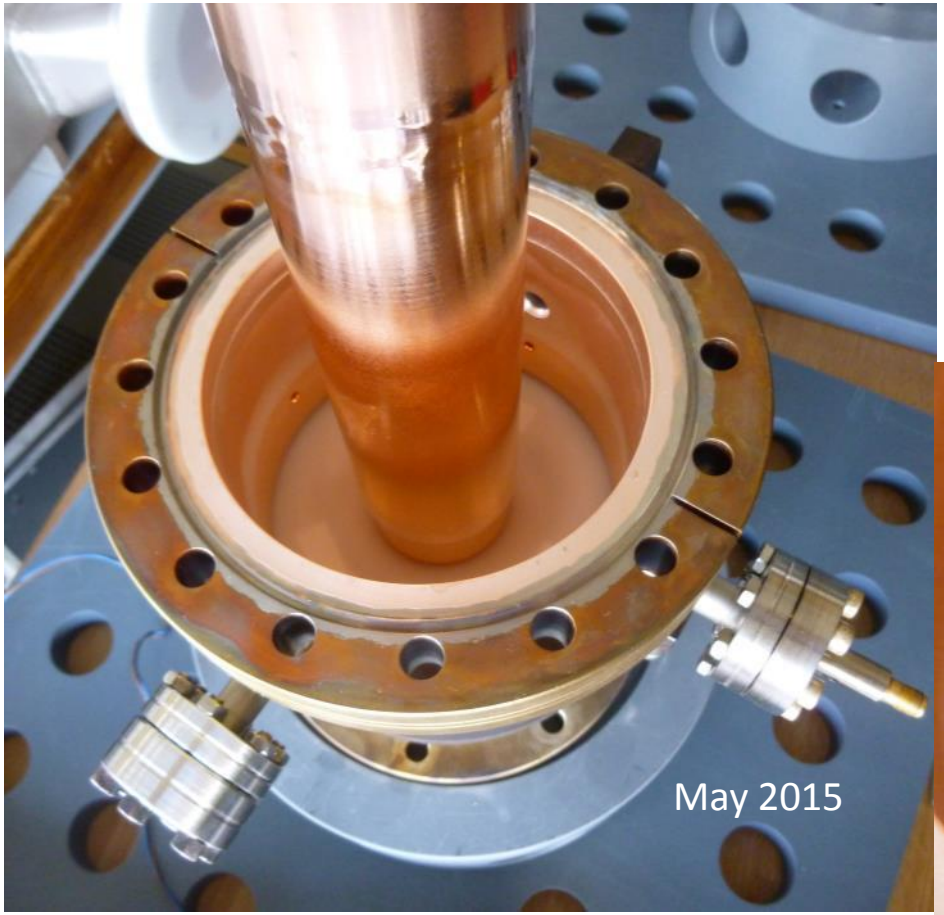
The antenna and RF window had previously been conditioned

Looking towards the RF window



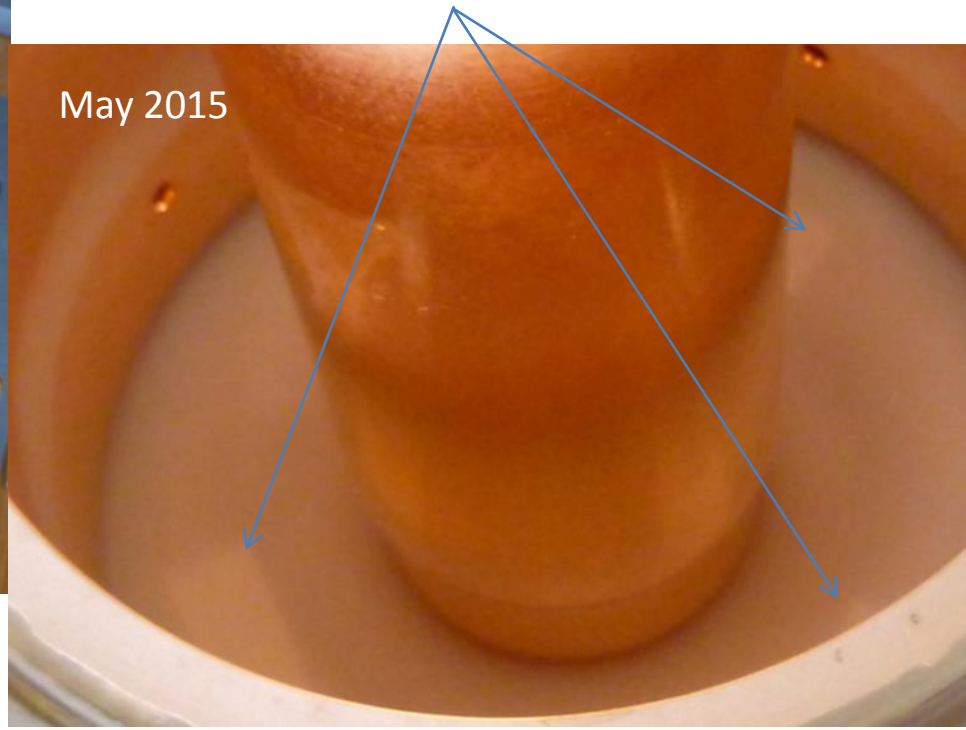


RF window vacuum side

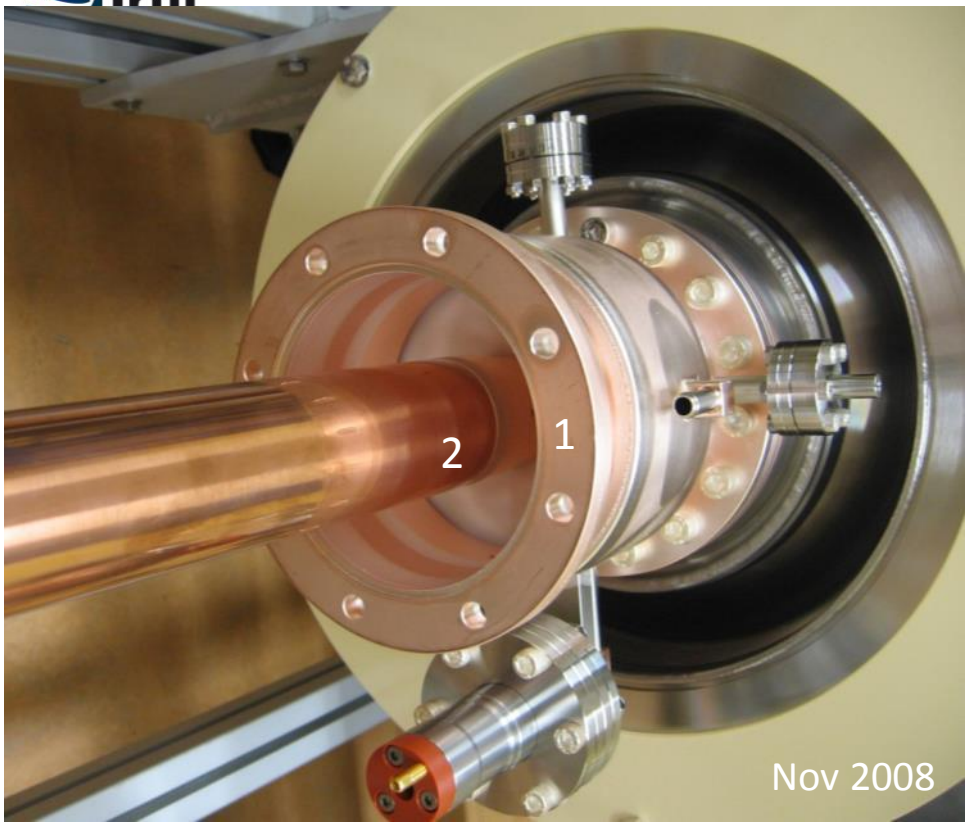


Cu layer and antenna aspect is unchanged since clean room assembly in 2008

Vacuum side of ceramic disk is now gray with spared rectangle areas



Consequence of wrong assembly of air part



Misalignement of (1) window IC and (2) dooknob IC → water leak at an early stage of RF conditioning. Arcing occured at O-ring gasket location (and destroyed it) Only repair was hand polishing of copper surfaces. TW and SW 1MW conditioning was performed afterwards.

Air side arcing

Picture shows the effect of several tens of arcs (sorry for the wrong white balance).
Cleaning of the sputtered copper was performed in-situ using diluted Nitric acid using swabs.

Air side arcing occured when running at full reflection on SC cavity 1MW forward power, 50 Hz, 2ms.

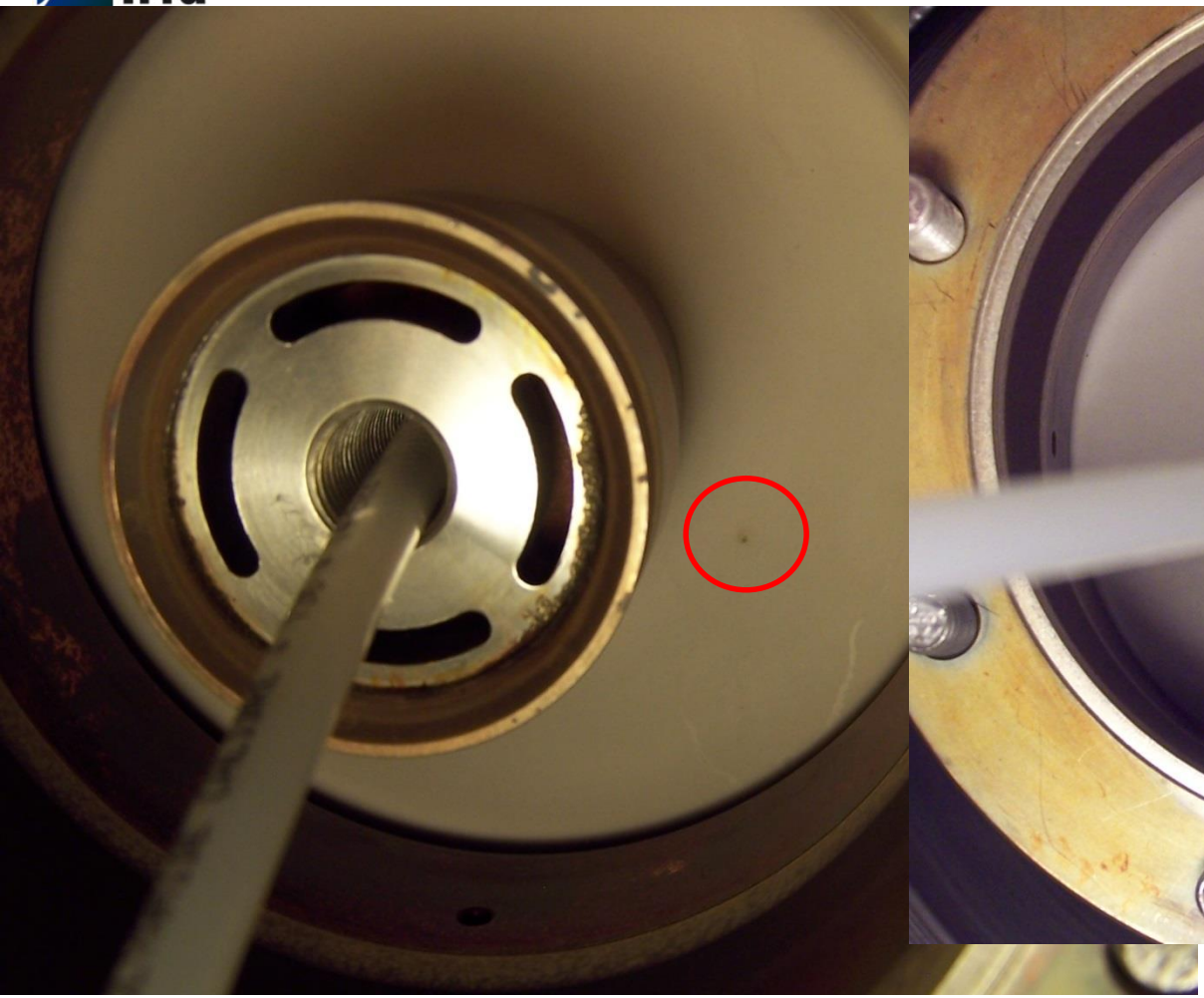
No arc detector on the air side at that time

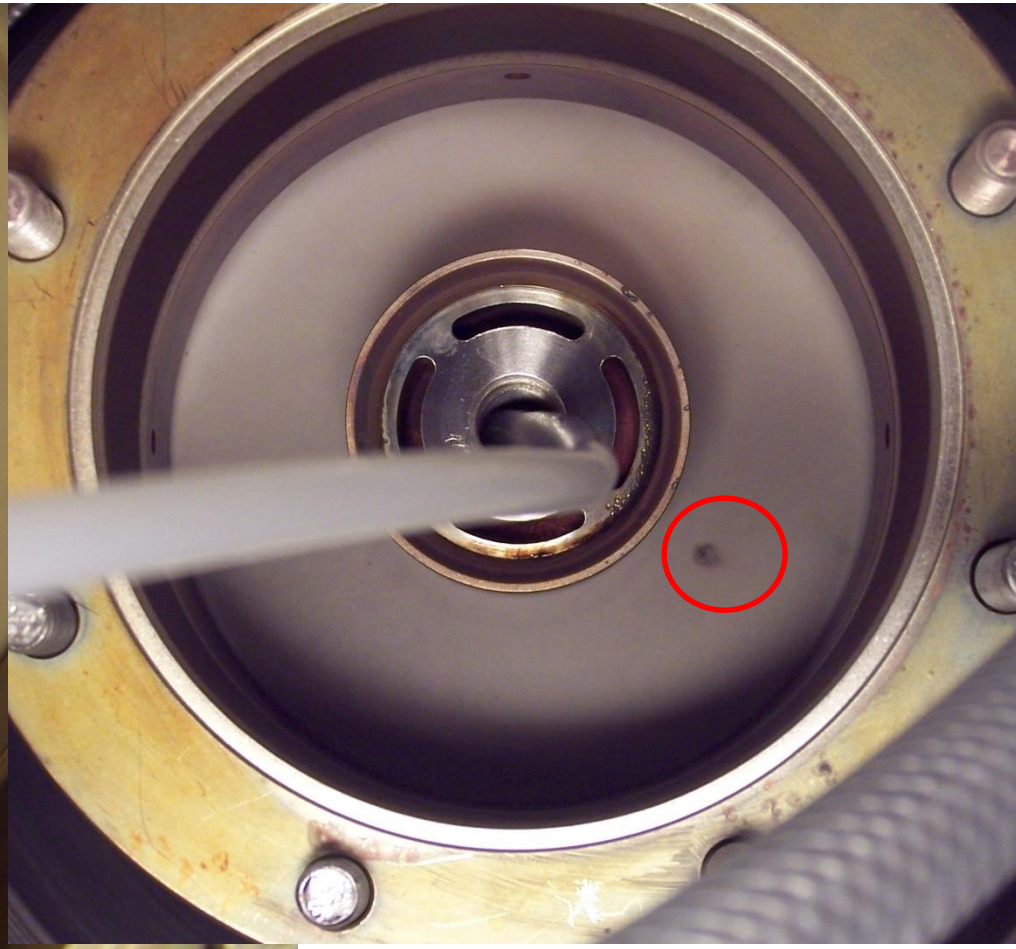
Window was protected by the vacuum-side arc detector

Window was cooled with dry N2 stream blowing on its air side.

Arcing stopped immediately when this forced cooling was disabled.

After cleaning



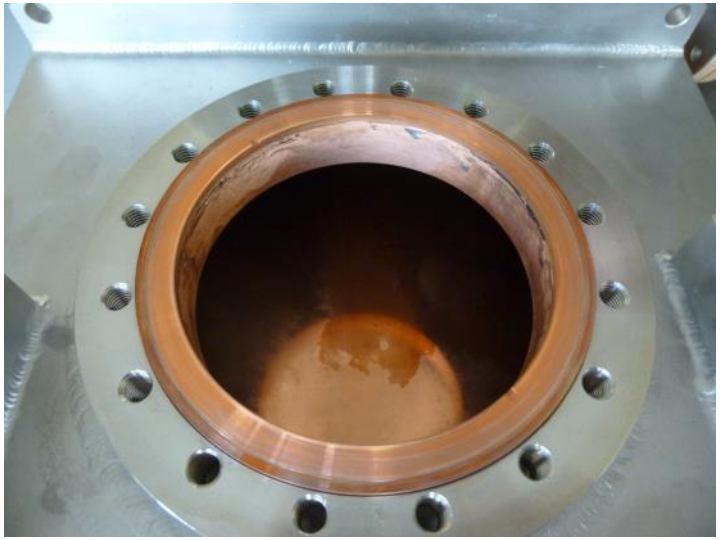


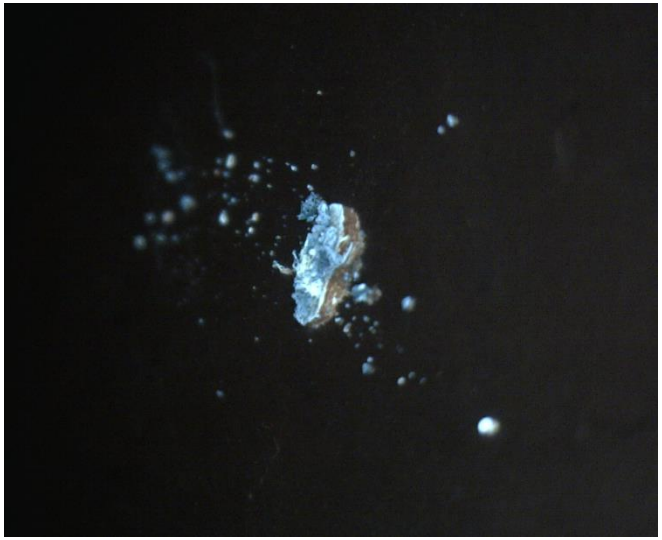
FPC was operated again after cleaning, arcs did not re-appear

HIPPI conclusion

What we tested that generally cause worries :

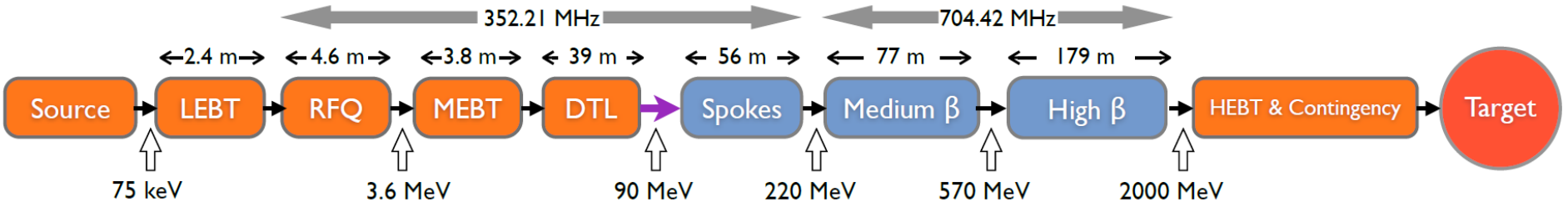
- Assembly on the cavity from the top in the clean room. No particle counting was performed in the 2009 assemblies but FE was not enhanced on the two test SRF cavities
- Massive antenna resting for years in horizontal position: no deflection observed
- More recently a new clean room test assembly of 1 HIPPI coupler was carried out in the new ISO5 clean room succesfully with particle counting
- The coupling waveguide aspect indicates it may have been the most difficult part to condition (Cu particulates were present inside)





The European Spallation Source linac

Beam power (MW)	5
beam current (mA)	62.5
Linac energy (GeV)	2
Beam pulse length (ms)	2.86
Repetition rate (Hz)	14



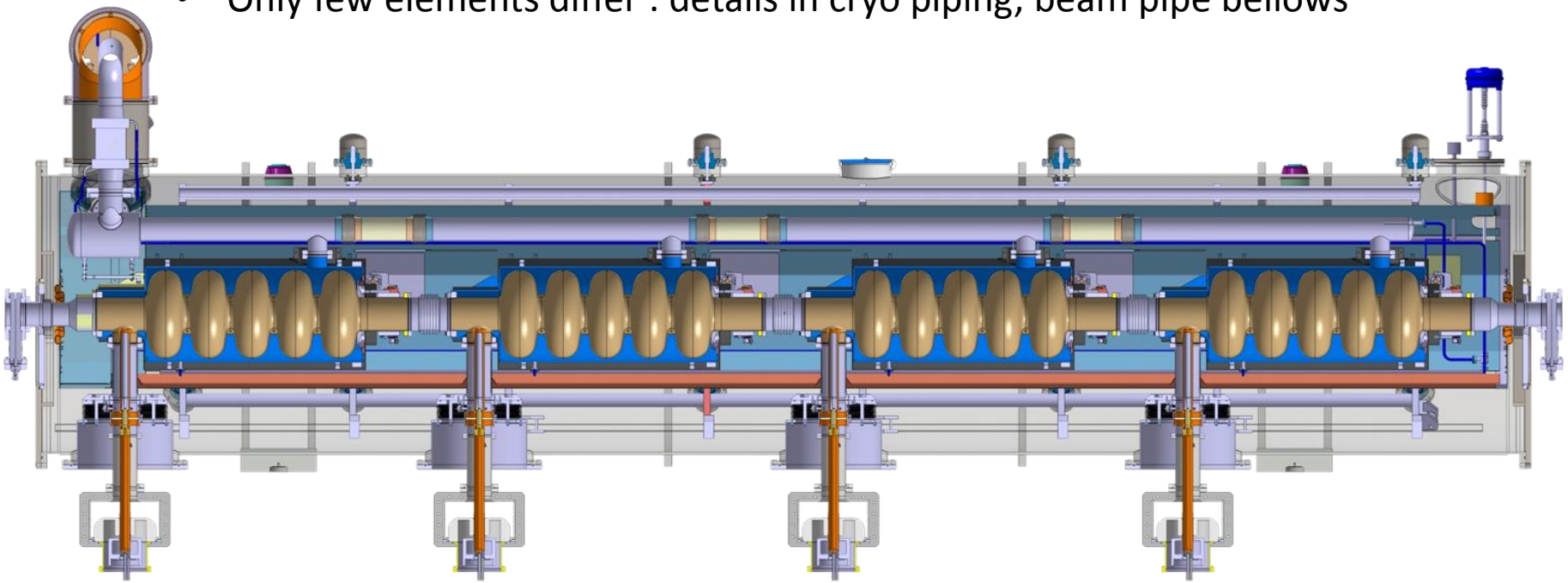
Segmented, superconducting proton linac, with RT focusing elements

	Num. of CMs	Num. of cavities
Spoke	13	26
6-cell medium β	9	36
5-cell high β	21	84

4-cavity cryomodules

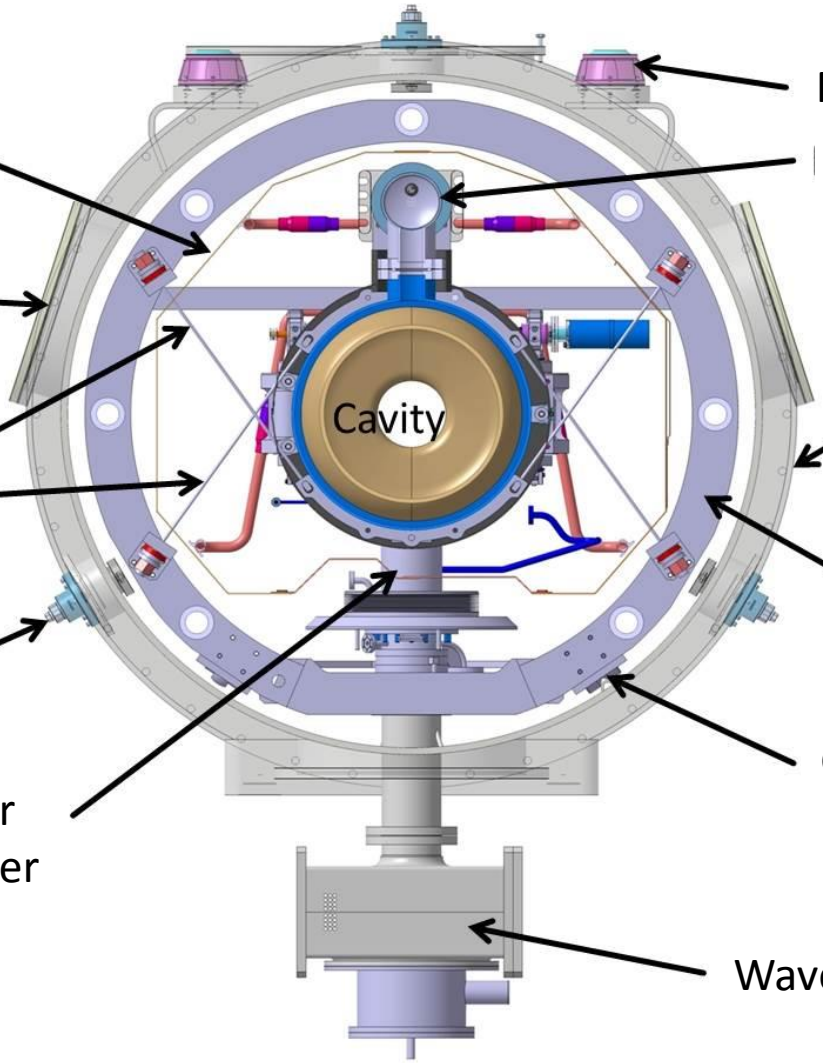
Similarity with SNS in size and purpose : reuse the same concepts

- Common design for medium and high beta
  - made sensible thanks to the small length difference between 6-cell medium and 5-cell high beta cavities
  - Main components are identical : vaccum vessels, thermal shield, supports, alignment system, etc.
  - Only few elements differ : details in cryo piping, beam pipe bellows



6600 mm

CM cross-section



50K Thermal shield (Aluminum)

Lateral port (CTS, alignment)

Tie rods (TA6V)

Positioning jacks (3 at 120°)

Power coupler

Positioning optical devices

Two phase He pipe

Vacuum vessel (stainless steel, 1200 mm diam.)

Space frame

Guide rail and wheel

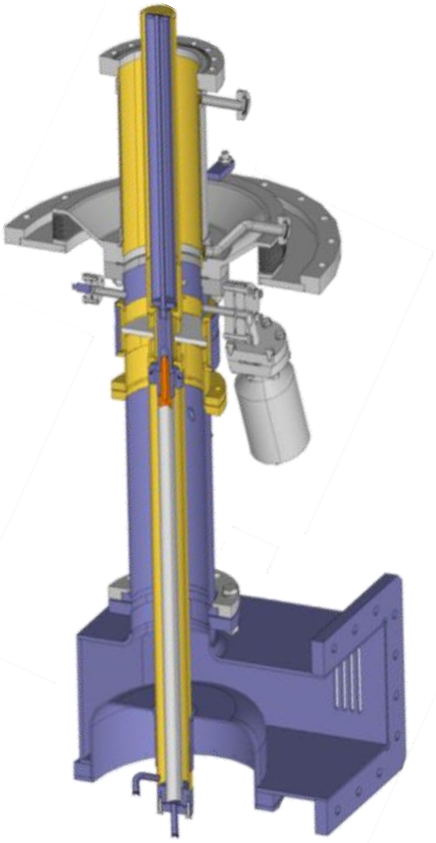
Waveguide transition

ESS 704 MHz power coupler peak power

	Optimus	Unit
$E_{acc\ Spoke}$	9	MV/m
V_{Spoke}	5.74 (L = 3 βλ /2)	MV
$P_{coupler\ Spoke}$	330	kW
$N_{Spoke\ modules}$	13	–
$E_{acc\ Mβ}$	16.79	MV/m
$V_{Mβ}$	14.36 (L = 6 β'λ' /2)	MV
$P_{coupler\ Mβ}$	860	kW
$N_{Mβ\ modules}$	9	–
$E_{acc\ Hβ}$	19.94	MV/m
$V_{Hβ}$	18.24 (L = 5 β"λ' /2)	MV
$P_{coupler\ Hβ}$	1100	kW
$N_{Hβ\ modules}$	21	–

D. Mc Ginnis

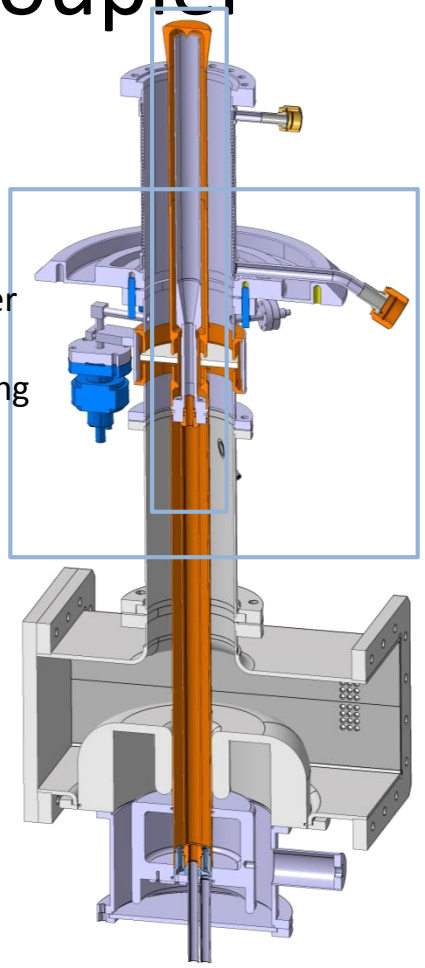
ESS Fundamental power coupler



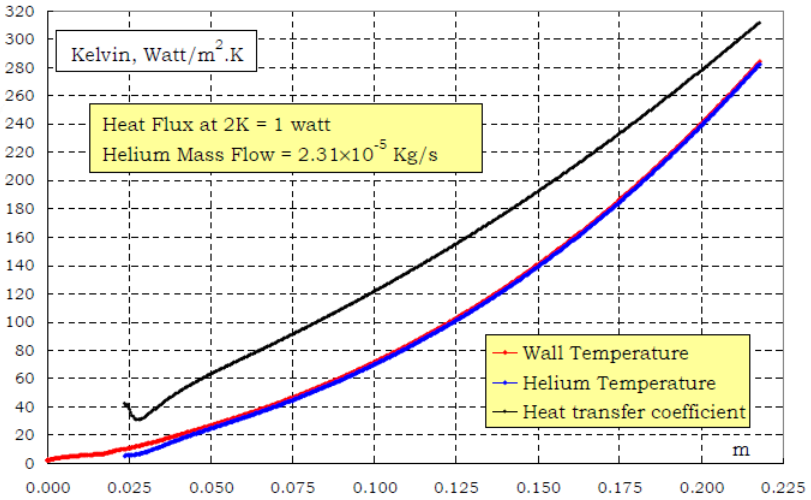
HIPPI coupler

CM integration

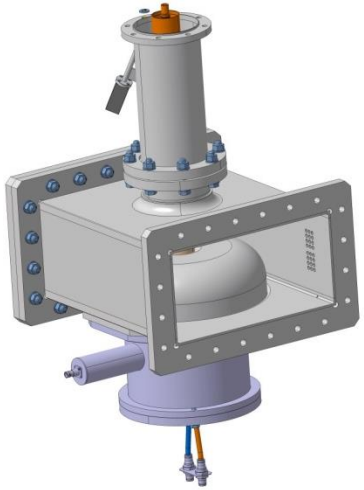
- Inner conductor
  - New flange, below is part of vacuum vessel
  - Conical tip for stronger coupling
- Diagnostic ports
  - Improved water cooling distribution channels
- VCRs

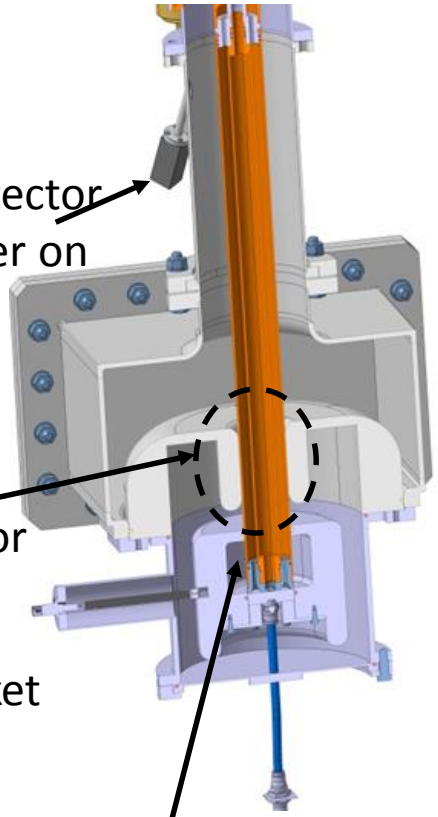


HV bias with RF trap



Doorknob transition





Air-side arc detector (photomultiplier on prototypes)

Kapton insulator

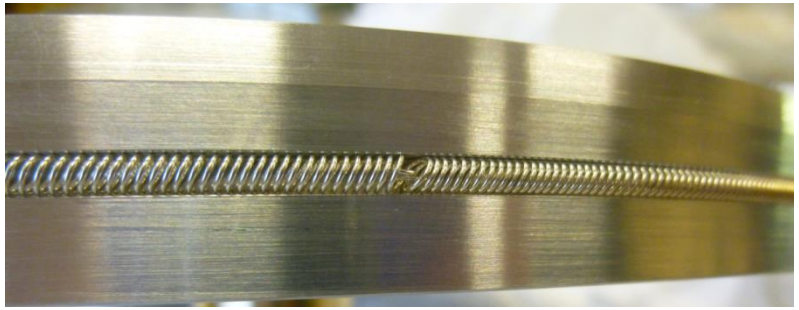
HV socket (<10kV)

RF trap

Water inlet and outlet

5 RF gaskets are required for the assembly

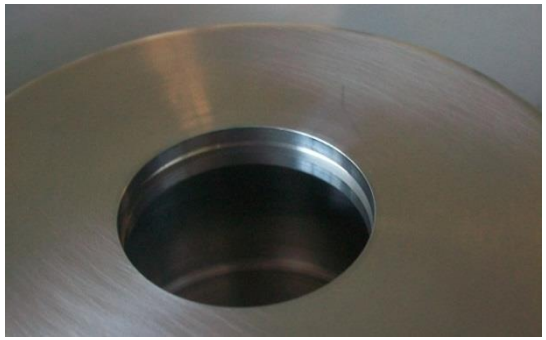
We use RF Spring-type gaskets

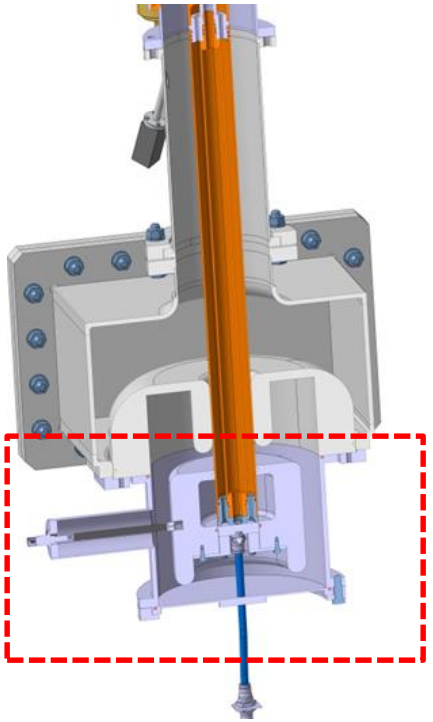


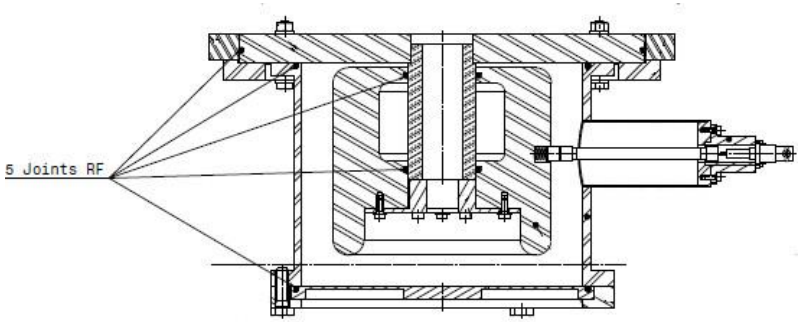
Gasket assembly mock-up of the RF trap

Checked :

- Gasket groove geometry in all configurations (coaxial inner groove and outer groove, flange type)
- Assembly/disassembly multiple times
- Wear caused by assembly is not significant

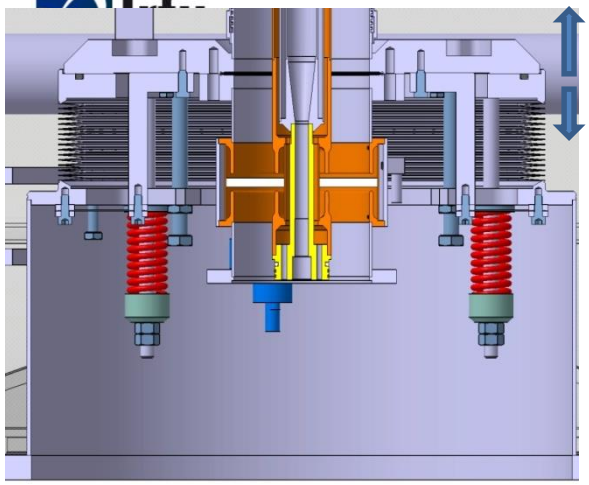






Mock-up with all 5 RF gaskets

Coupler/vessel interface

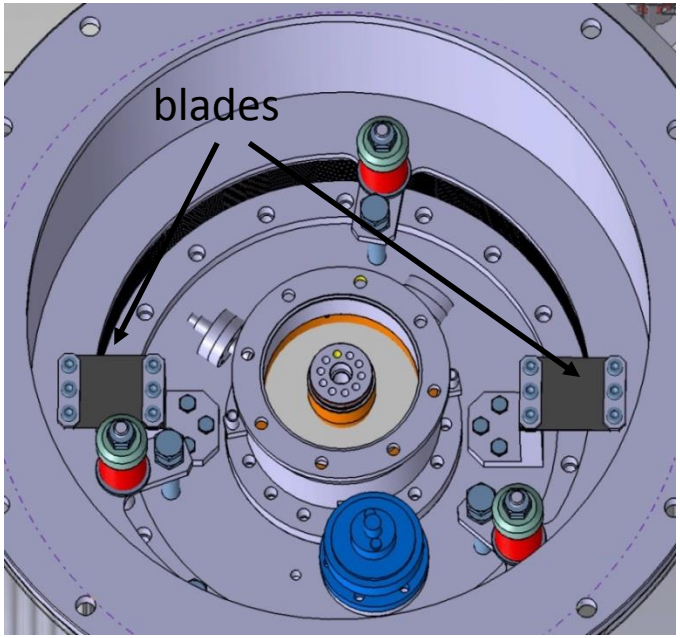


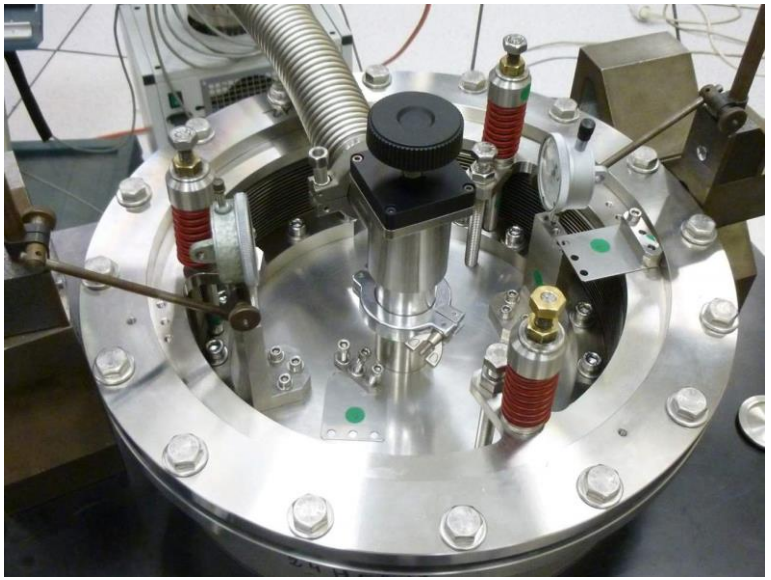
- Large flange due to vacuum gauge footprint

→ 10kN force due to atmospheric pressure needs to be compensated

→ Adjustable springs+stops. The FPC is stiff, vertical flange motion must be possible to accomodate thermal shrinkage of coupler and cavity

- The coupler remains at a fixed longitudinal position at all times using two blades



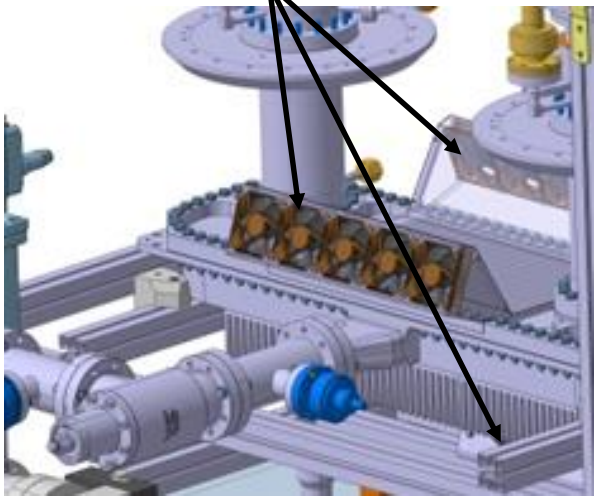


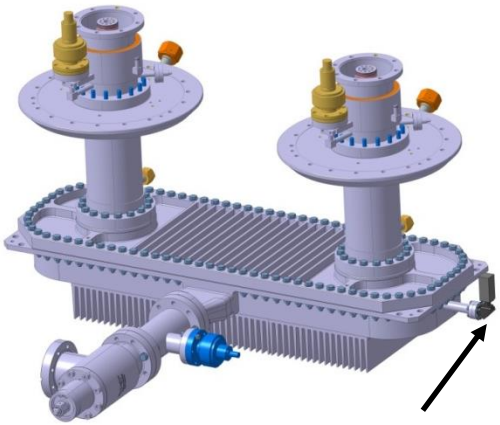
A mock-up with the nominal bellow and flange dimension has been built to check the concept of pressure compensation and choose the proper springs

Conditioning waveguide

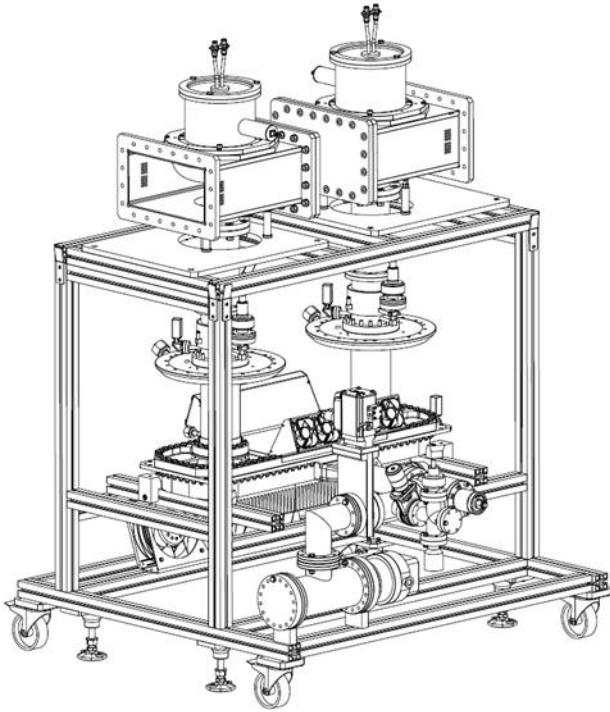
- Full stainless steel designed (no copper coating). Dismountable (as Eric's 700 MHz test box). Top cover can be Cu deposited if first tests prove it is necessary
- Air cooling designed accordingly ;
  - heat sinks + fans on bottom plate
  - Channeled air flow with push-pull fans on the top
- Arc detector added in order to have the opportunity to distinguish between window arcs and waveguide arcs.

Fans



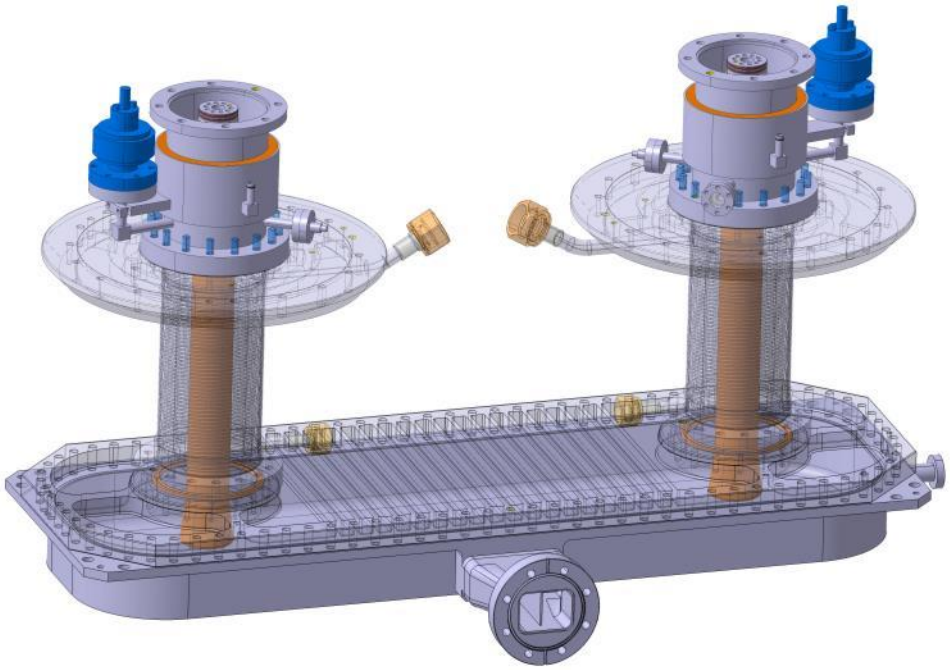


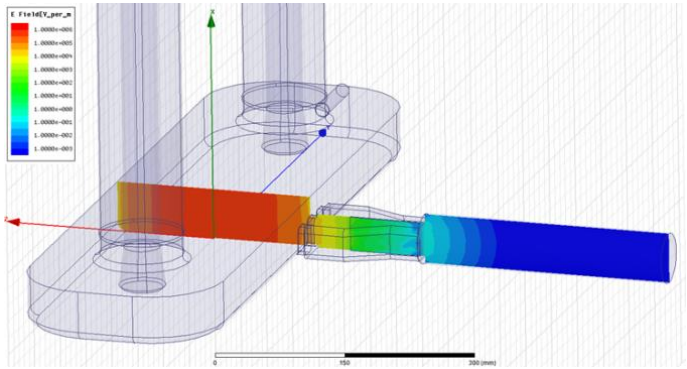
Arc detector

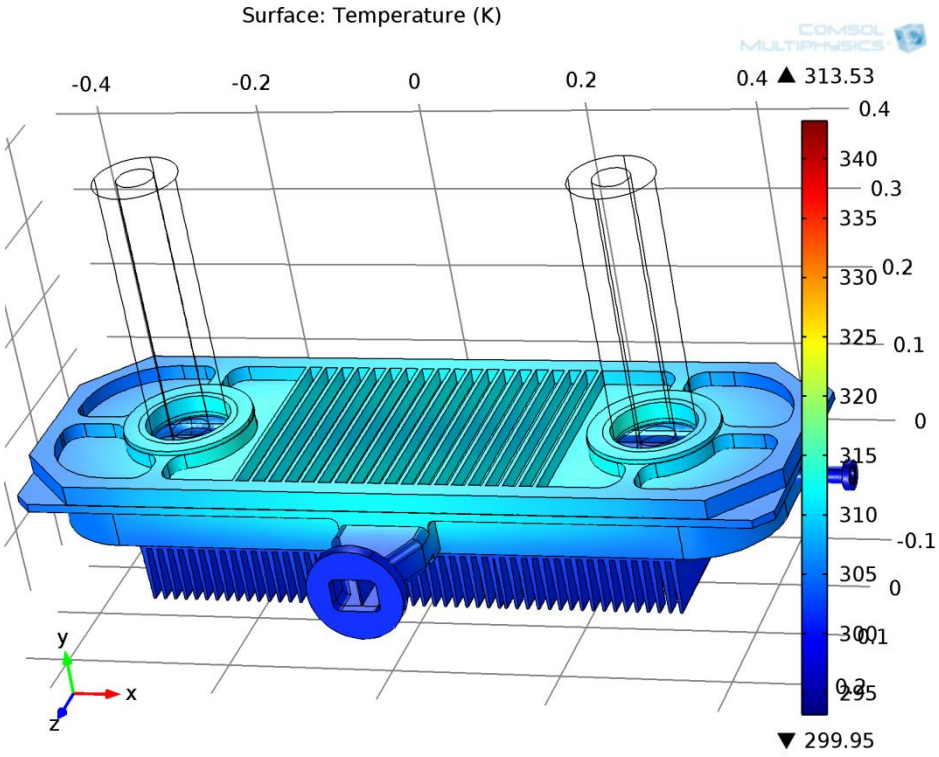


ESS FPC test box design

- Full stainless steel design
- Maximum access with two-part construction
- Seal : aluminum wire
- Air cooling on top and bottom



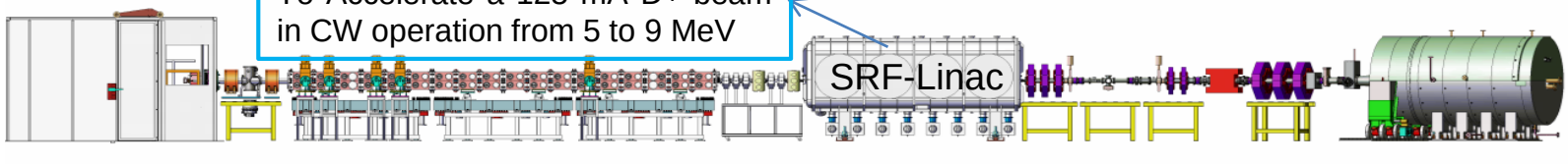


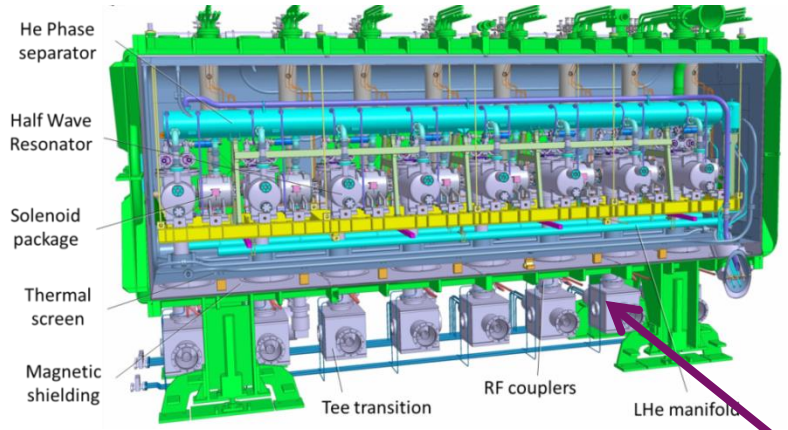


IFMIF POWER COUPLER FOR LIPAC

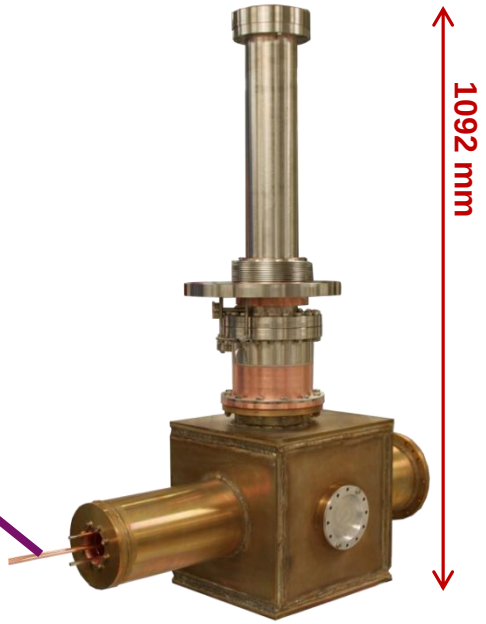
Linear IFMIF Prototype Accelerator to be tested in Rokkasho - Japan

To Accelerate a 125 mA D+ beam in CW operation from 5 to 9 MeV

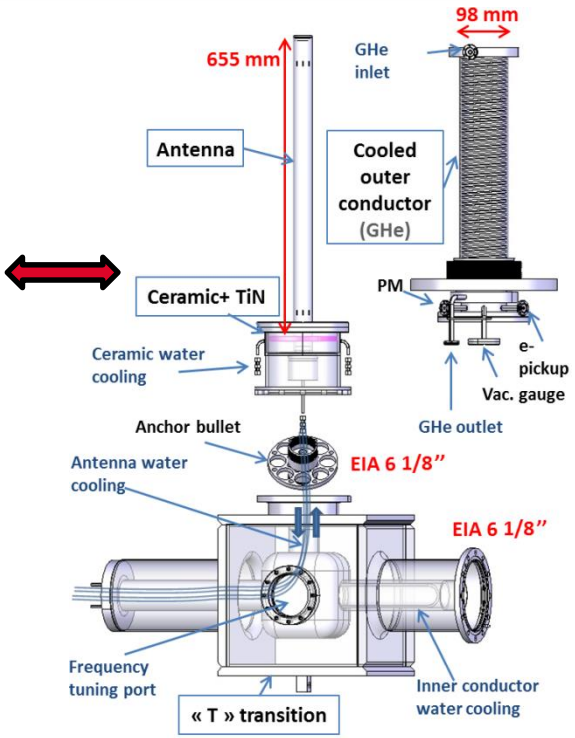




SRF-LINAC



IFMIF Power Coupler



Power Coupler Specifications for LIPAC:

- Frequency: 175MHz
- Qext: 6.5×10^4
- Maximum nominal operating RF power: 70 kW CW
- RF power validation needs : 100 kW CW in Travelling Wave (TW) and Standing Wave (SW)

CLEANROOM ASSEMBLY

Power Coupler Assembly at Saclay

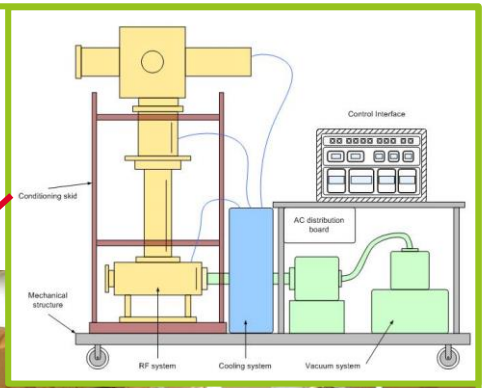
Transportation

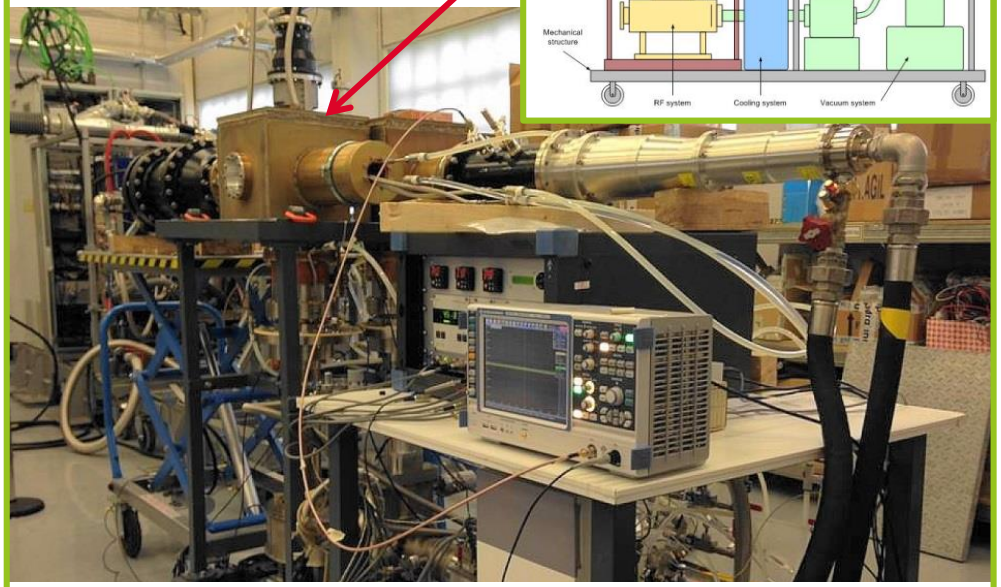
Power Coupler Assembly on Test Box at Madrid

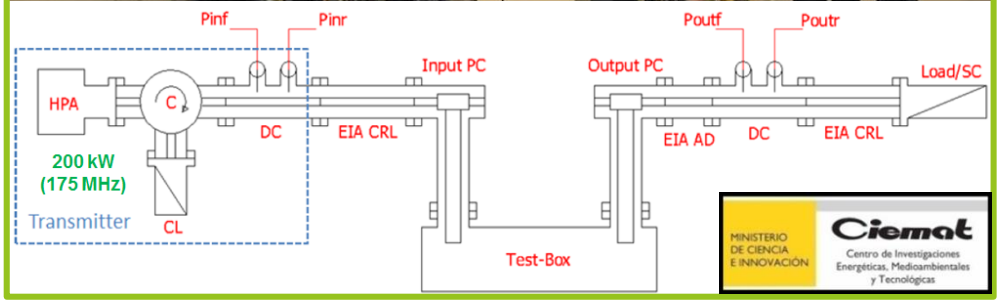
- Prototype Power Coupler Pair manufactured
- Test box manufactured and qualified
- Assembly operations performed in ISO5 clean rooms
- Particle counting check performed before each critical assembly operation

RF POWER TEST STAND AT CIEMAT

- **In-situ baking :170°C**
- **Water Cooling : 27°C**
- **Diagnostics:** E-currents / Vacuum / Light / Temperature







RF Power Validation Criteria:

1) TW CW power up to 100 kW.

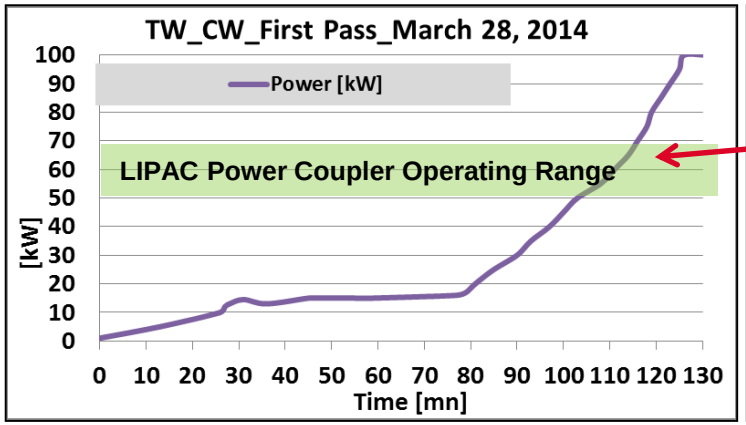
2) SW CW power up to 100 kW with RF field configuration giving a maximum electrical field on ceramic window for PC Proto-1, then PC Proto-2.

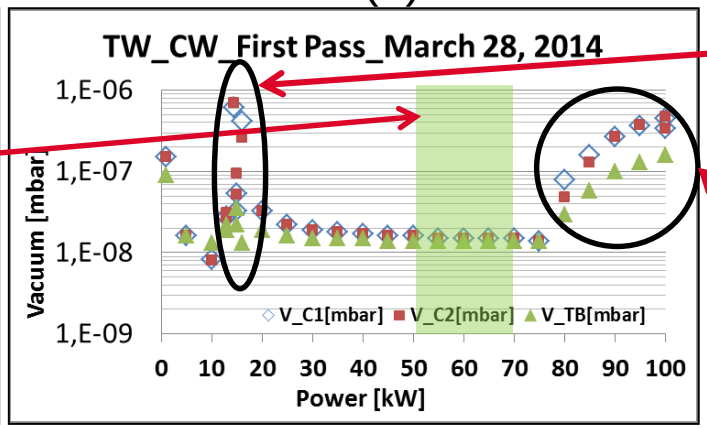
RF Power Conditioning Steps :

- TW pulsed RF processing (0 → 100 kW) : From 20µs (2 Hz) to 400 ms (2Hz)
- TW CW RF processing up to 100 kW
- SW RF processing (from pulsed to CW) (0 → 100 kW) :
  - With max E field on the upstream ceramic window
  - With max E field on the downstream ceramic window
  - With max E field on six other intermediate positions.

RF POWER VALIDATION RESULTS

TW CW RF Power Validation Result (1)

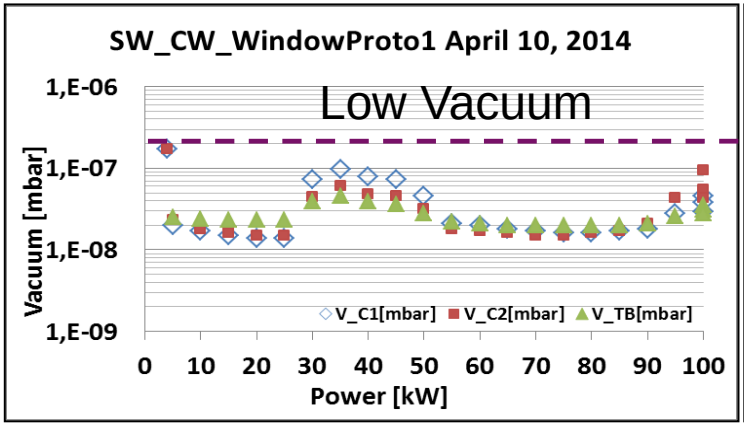


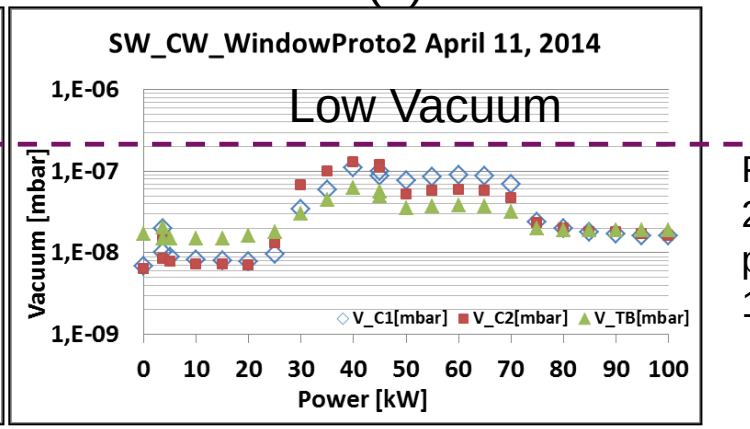


Vacuum increase due to Multipacting

Vacuum increase correlated with the test box temperature increase

SW CW RF Power Validation Result (2)



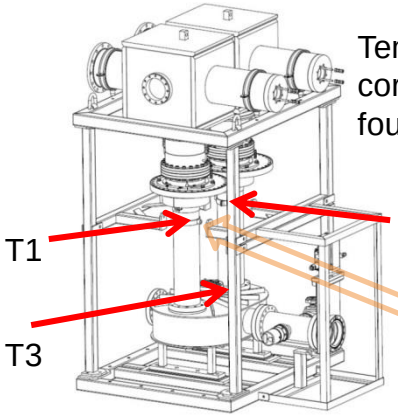


Pressure less than 2×10^{-7} mbar for all the power ranges from 0 to 100 kW CW SW.

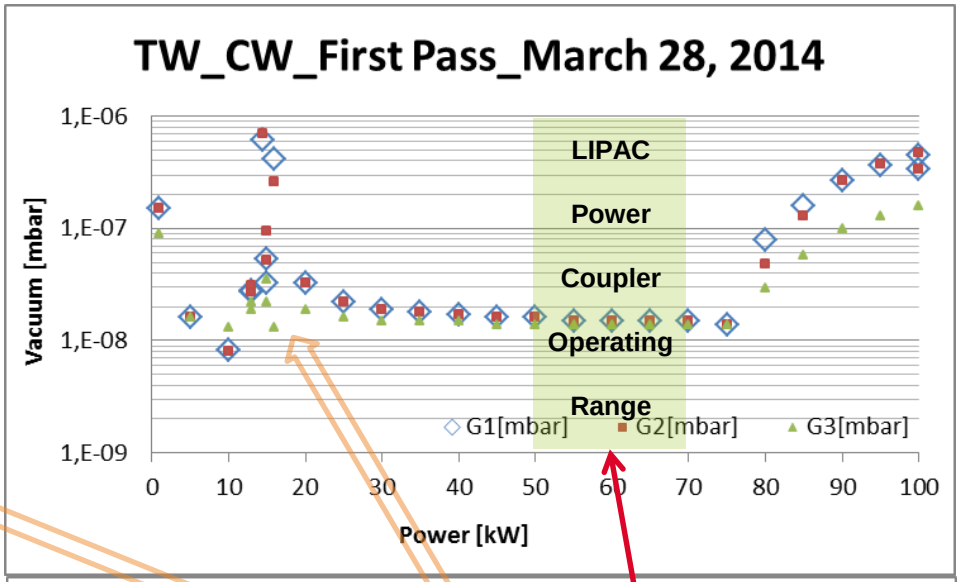
Test Results:

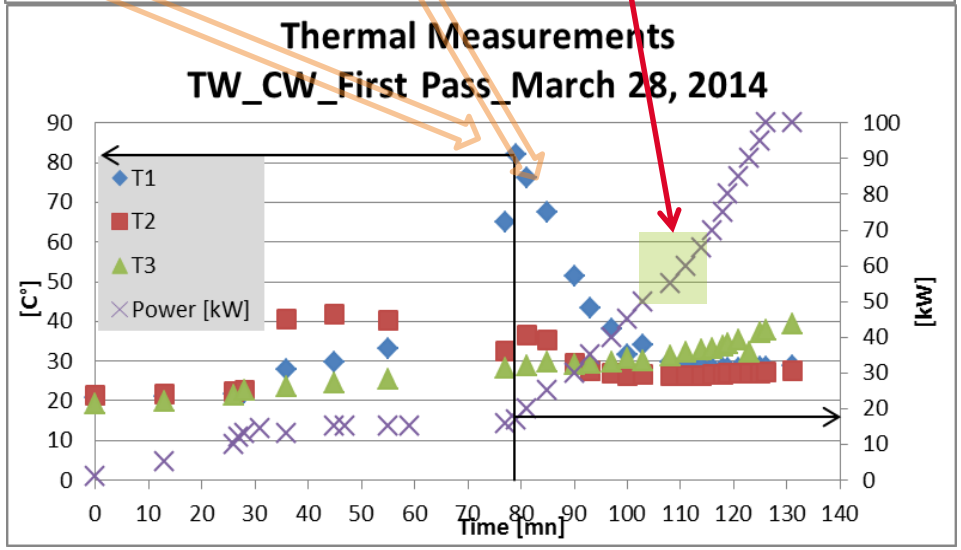
- Power validation objective has been reached: **100 kW CW (TW/SW)**
- Power Coupler behavior satisfactory : Smooth and easy power increase, in general.
- Low vacuum and no e-current measured for the Coupler operating power ranges at the end of the RF processing

MULTIPACTING DURING RF PROCESSING



Temperature sensor positions corresponds to the hottest locations found experimentally





TW_CW_ First Pass: MP for Power between 12 kW and 18 kW:

- ➔ Vacuum interlocks.
- ➔ Low current signal are measured.
- ➔ Temperature increase : Max located on the cooling outer conductor (up to 82°C).
- ➔ MP effect is more important in the upstream coupler.

Additional RF processing of the MP was performed after the RF power validation (TW&SW):

- ➔ MP on the downstream coupler almost totally processed.
- ➔ MP on the upstream coupler is limited to a narrow power range (13 to 14 kW), but generates important temperature increase at this power level.
- ➔ No interlock is generated and power can be increased to avoid this region.

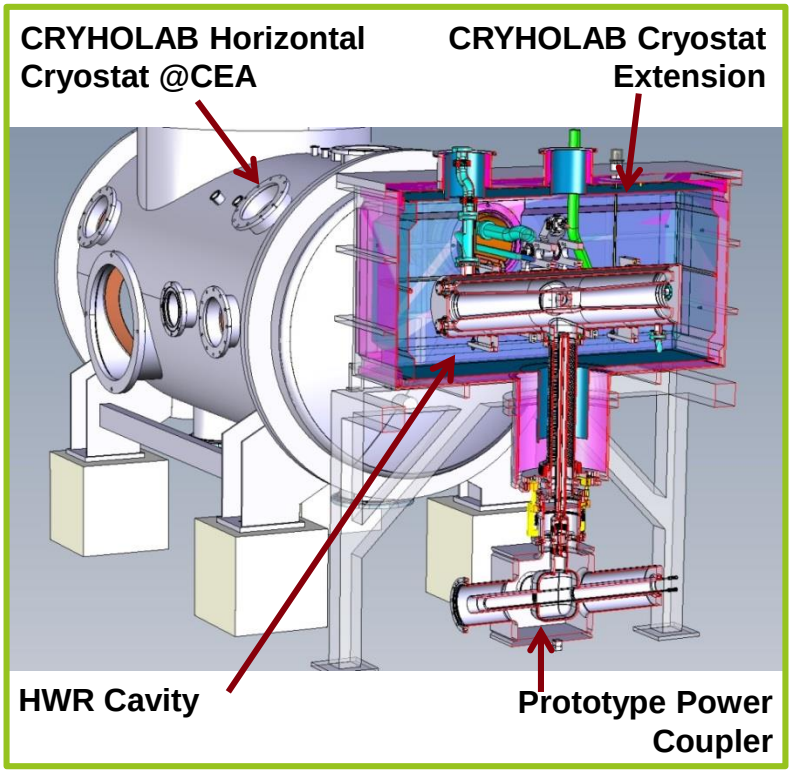
SUMMARY AND PERSPECTIVES

Summary:

- Two (IFMIF/LIPAc) Power Coupler Prototypes were manufactured and RF power tested @ RT
  ➔ **Validation for RF power operation up to 100 kW CW in TW & SW configurations**
- Manufacturing of **8 Series Power Couplers** for LIPAc is on going
- MP around 13 kW RF power level is not limiting for the Coupler operation and it has been partially processed: More investigation is planned.

Next stages:

- Complementary tests **up to 200 kW** (in pulsed mode)
- **Cold test** of one of the validated **Prototype Couplers + HWR cavity** (Extension of the existing Cryostat (CRYHOLAB) to make the test possible)
- First pair of the Series Power Couplers expected for May 2015



Thank you

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G. Ferrand,
X. Hanus,
H. Jenhani,

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